VARIATION OF 3D CAMERA BASED ANTHROPOMETRY FOR PREDICTION OF CEPHALOPELVIC DISRPORPORTION IN ETHIOPIA

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SUMMARY

Cephalopelvic disproportion (CPD) is a dangerous pregnancy complication that often leads to maternal and perinatal morbidity or mortality if a cesarean section is not performed. Although for most people in the United States, the cesarean section procedure is easily accessible, this is not the reality for many women throughout the world. In Ethiopia, where the cesarean section procedure is often not easily accessible, obstructed labor occurs in nearly 13% of pregnancies, with nearly 65% of these cases occurring because of CPD. Accurate and timely referral of pregnant women who are at high risk of CPD to referral hospitals where they can obtain a cesarean section has the potential to save lives at birth. The Gleason Lab has investigated the use of 3D-camera based anthropometry as a tool for CPD risk calculation through the development of an algorithm that obtains anthropometric measurements from 3D scans. The 3D Cameras studied are the Occipital Structure Sensor and the Microsoft Kinect sensor, which are cameras in research and commercial use worldwide. This work extends that research by conducting variability and longitudinal studies to evaluate the variation of the measurements obtained by this algorithm for the two 3D-camera based approaches of Structure and Kinect and compares their variation to measurements obtained by traditional anthropometry. Results found that the Structure approach often had similar variation or less variation than traditional anthropometry, and Kinect was often had similar variation or greater variation than traditional anthropometry. These results illustrate the robustness of the approach of using Structure 3D-camera based anthropometric measurements for the prediction of CPD and encourage further development of this approach for eventual use in Ethiopia.

CHAPTER 1: INTRODUCTION AND BACKGROUND

Cephalopelvic Disproportion

Maternal death, one of the most tragic crises facing the health sector, is often entirely preventable. Although the global health care and biomedical engineering community have made great strides in science and technology to support women during childbirth, these improvements do not reach everyone. The World Health Organization (WHO) states that in the year of 2017 alone, nearly 300,000 women died due to preventable complications from pregnancy and childbirth, which is equal to 810 women dying every day, simply because of where in the world they happen to reside. Maternal deaths are disproportionately distributed throughout the world; 94% of all maternal deaths occur in low and lower-middle income countries. Although these rates have improved over the past two decades, as the global maternal mortality ratio, which is the number of maternal deaths per 100,000 live births, dropped 38% from 2000 to 2017, the global healthcare community still has abundant improvement to make to eliminate those annual 300,000 preventable maternal deaths (World Health Organization, 2019),.

One common reason for preventable maternal death is the absence of medical professionals and equipment at delivery to perform the cesarean section procedure. When a mother has a serious pregnancy complication, the cesarean section procedure is often life saving for both the mother and baby. One such pregnancy complication that requires cesarean section is obstructed labor, in which the baby is mechanically unable to progress through the birth canal. Obstructed labor is most frequently caused by cephalopelvic disproportion (CPD), which is the mismatch between pelvis size and baby size; the baby is too big to be born vaginally through the mother's small pelvis. CPD can arise through a variety of factors, such as if the mother is pregnant at a young age, is naturally short of stature, or she suffered from malnutrition during her youth, causing stunted growth. Without the cesarean section, CPD related obstructed labor can lead to mortality for both the mother and baby, or serious forms of morbidity for the mother and baby. If they survive, mothers who deliver vaginally despite obstructed labor are at high risk of fistula, postpartum hemorrhage, shock, paralytic ileus, uterine rupture, and sepsis. Infants are at high risk of neonatal sepsis, convulsions, facial injury, and severe asphyxia. Therefore, there is pressing need to ensure every mother who experiences obstructed labor has access to the cesarean section procedure. If cesarean section is available, the complications that can arise from CPD can be eliminated, thus saving the mother and baby. It is for this reason that CPD is not a well-known complication in many countries like the US, where an emergency cesarean section is often available for mothers. However, for many women in the world, this procedure is not easily accessible, making CPD a very dangerous condition.

CPD in Ethiopia

One location where CPD-related obstructed labor causes significant problems for mothers and babies is the country of Ethiopia, where this work is focused. In 2021, Ayenew published a systemic review of 16 primary studies based in Ethiopia, with a total of over 28,000 mothers who gave birth in Ethiopia included, and found that the estimated incidence of obstructed labor of mothers who deliver in Ethiopia is 12.93%, and CPD was the cause of 64.65% of these obstructed labor cases (Ayenew, 2021). The most common maternal-fetal complications from these cases of obstructed labor were sepsis (38.08%), stillbirth (38.59%), postpartum hemorrhage (33.54%), uterine rupture

(29.84%), and maternal death (17.27%). The majority of women who were diagnosed with obstructed labor were from rural areas (77.85%), which Ayenew proposes might be because in these areas health facilities that can perform cesarean section are often very far away, as demonstrated by the low density of hospitals in Ethiopia, even in areas with high population (**Figure 1**)(Maina et al., 2019). The health care facility birth statistics highlight the contrasting access between the urban and rural areas of the country, with the percent of births occurring in a health facility being 70% in urban areas, where access to hospitals is higher, and only 40% in rural areas, where access is more challenging (Ethiopian Public Health Institute (EPHI), 2019).

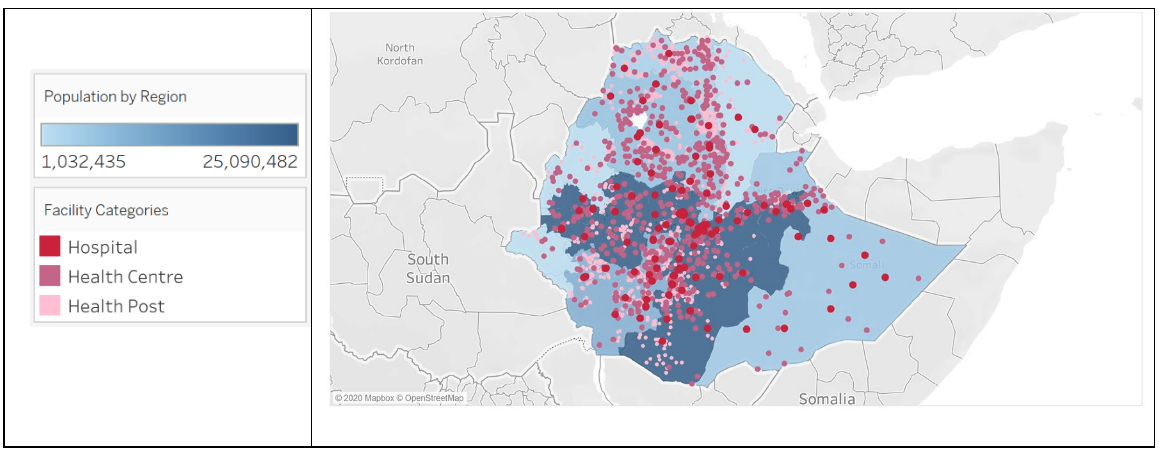

Figure 1 – Healthcare access in Ethiopia.
This map shows the geographic distribution of population density of Ethiopia, overlayed with the locations of Hospitals, Health Centres, and Health Posts. As Health Posts and Health Centers most likely are unable to perform cesarean sections, mothers must travel to a hospital for this procedure. For many women in Ethiopia, this is too far of a journey to be realistic without abundant planning. (Maina et al., 2019).

As of 2019 in Ethiopia, only 48% of mothers went to a health facility for delivery **(Figure 2).** However, demographic data also indicates that 74% of women receive some sort of antenatal care from a healthcare provider during that pregnancy, showing that there are women who do receive antenatal care, but then have a home delivery (Ethiopian Public Health Institute (EPHI), 2019). Therefore, these antenatal care visits provide an opportunity for women to receive information about their unique risk for complications like CPD, and for them to be urged to plan ahead to be able to give birth in a health facility. The following belief is based upon the hypothesis that accurate and timely referral of at-risk mothers to health facilities where cesarean section is available could reduce maternal and perinatal mortality and morbidity.

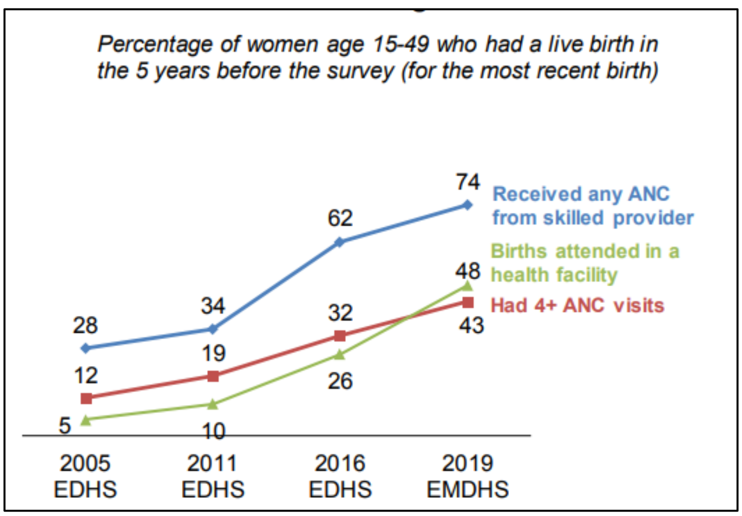

Figure 2 – Trends in antenatal care and delivery in Ethiopia.
The 2005, 2011, and 2016 data is from each of those years' Ethiopia Demographic Health Survey (EHDS), the 2019 data is from the Ethiopia Mini Demographic Health Survey (EMDHS). Antenatal care is abbreviated as ANC.

Historical methods for prediction of CPD

Efforts have been made to develop strategies for prediction of CPD for over a century, but these existing methods are often not very predictive, or are not widely feasible in Ethiopia. Internal physical measurements of the pelvis and fetus size can be obtained and then used to make an estimation about CPD risk. For example, radiological pelvimetry can be done with X-Ray, Magnetic resonance imaging (MRI), and computerized tomography (CT) technology by quantifying the size of pelvic planes, which when combined with ultrasound measurements of the fetal size can be used to develop risk scores for CPD (Abitbol et al., 1991; Caldwell & Moloy, 1933; Friedman & Taylor, 1969; MENGERT, 1948; Morgan et al., 1986; Spörri et al., 2002; Thurnau & Morgan, 1988). However, the effectiveness of this approach is controversial, as it has not been properly evaluated by clinical trials (Rozenberg, 2007). Additionally, this approach is often not feasible for most of Ethiopia, where MRI, CT, and ultrasound technology are often not available. Additionally, x-ray exposure to the fetus can be harmful and is best to be avoided.

Alternatively, external features have also been explored as a technique for predicting CPD. The method of clinical pelvimetry involves highly skilled healthcare professionals assessing the size of the pelvic cavity through vaginal palpation of specific bony landmarks in the pelvis and estimating the distance between them. However, this approach is only mildly predictive (Maharaj, 2010). For example, in an analysis of 177 Nigerian primigravidae that had clinical pelvimetry performed, although clinical pelvimetry findings had a significant correlation for the baby's health after delivery, as indicated by one minute Apgar scores, there was no significance correlating clinical pelvimetry findings with mode of delivery (Adinma et al., 1997). This indicates that this approach is not sufficient to predict if a woman needs a cesarean section procedure, and other methods should be explored. Additionally, this approach would also not be feasible in Ethiopia as it relies on highly skilled personnel, and Ethiopia has an extraordinarily low density of doctors (.077/1000) and nurse/midwifery personnel (.714/1000) (World Bank, 2018).

Basic anthropometric measurements have been studied as predictors of CPD. Common measurements include height, shoulder width, various measurements around the hips, and even foot length (Adadevoh et al., 1989; Bansal et al., 2011; Chen et al., 1982; Connolly et al., 2003; Emanuel et al., 2004; Hanzal et al., 1993; Kappel et al., 1987; Kennedy & Greenwald, 1981; McGuinness & Trivedi, 1999; Okewole et al., 2011; van Bogaert, 1999). These measurements are more feasible to obtain than those needed for clinical pelvimetry, as they require less specialized skill to obtain. However, when measured with a tape measure, these values are often only “fair” predictors, and have high variability (Bansal et al., 2011; Connolly et al., 2003; Liselele et al., 2000; Möller & Lindmark, 1997; Shepard et al., 1998). It is for this reason that the Gleason Lab has investigated using 3D camera-based anthropometry to obtain similar anthropometric measurements.

3D-camera based prediction of CPD

3D sensors such as the Kinect Camera™ (Microsoft, Redmond WA) and Structure Camera™ (Occipital, Boulder CO) have potential to be effective tools for the prediction of CPD through obtaining anthropometric measurements. These sensors have the advantages of being low-cost (Kinect ~200 USD + cost of laptop, Structure ~600

USD + cost of iPad), reusable, require no disposable materials, and pose no health risks due to the lack of ionizing radiation. 3D cameras have been studied in a variety of other contexts to obtain Anthropometric measurements. In healthcare, 3D scanning technology has been used to measure the sizes of specific features, such as the arm for lymphedema detection (Binkley et al., 2020; Vitali et al., 2021), the legs for orthopedic applications (Redaelli et al., 2018), and the face for surgery (Knoops et al., 2017). The most prominent use of 3D scanning of the full body has arisen in the garment industry, where they have become increasingly common throughout the industry for the proper sizing of apparel to meet the physiological sizes of a manufacturer's market demographic (Marfell-Jones et al., 2006). The International Organization for Standardization (ISO) even has issued guidelines in attempts to internationally standardize the process of extracting body measurements from 3D scans (ISO, 2018). However, the apparel industry often uses much more expensive, high footprint, industrial 3D scanners, which would not be suitable for the application of this research.

It is for this reason that analysis of the Structure and Kinect cameras in our specific application is particularly necessary for our work. Existing applications of 3D scanning based anthropometry do not focus on obtaining anthropometric measurements from pregnant women, who have distinct body shapes compared to non-pregnant women. As the CPD risk score studied by the Gleason Lab utilizes measurements that are unique to pregnant women, such as various measures within the torso, it is important to develop a tool that can obtain these measurements. Additionally, as women around the world have varying body shapes, it is also valuable to develop a platform that particularly is designed for the population of Ethiopian pregnant women.

The Kinect and Structure cameras used in this study both generate 3D point clouds from participants. The Kinect sensor only obtains one side of the participant's body, either their front or back side. It uses both a color camera and depth sensor for its acquisition, using the time-of-flight principle with infrared light to obtain the 3D model of point clouds of the participant, as well as 25 "Kinect joint" locations which approximate various physiological landmarks. To obtain images, the Kinect sensor must be connected to a laptop, which houses the acquisition software. One major disadvantage of the Kinect platform is that the sensor and laptop must be continually connected to external power, which is not always available in Ethiopia. The other camera used in this study is the Structure sensor, which obtains a complete 3D model of the participant body using Structured light technology. The Structure sensor is designed to be attached to an iPad™ (Apple, Cupertino CA), which houses the acquisition software for the tool, and enables the device to be both mobile and have the advantage of only requiring intermittent charging. The Structure sensor obtains a scan by the user pointing the tool at an object, and then circling the object until a complete 3D model is obtained by the tool. One disadvantage of this tool is that the participant must stay completely still while the scan is being obtained for the image quality to be optimal.

The 3D point clouds generated by these scans can be used to identify landmarks on the body, which then can be used to calculate various landmarks **(Figure 3).** The Gleason Lab has already conducted two studies on this topic. Preparation for these studies included training Ethiopian nurses on how to use the 3D scanning tools, developing an algorithm that could identify anthropometric measurements from these 3D scans, and creating a risk score for the prediction of CPD from these measurments. The protocols involved Ethiopian nurses obtaining 3D scan data and traditional anthropometric tape measurements of Ethiopian pregnant women participants, and obtaining pregnancy outcome information for these participants (Gleason et al., 2018; Tolentino et al., 2019).

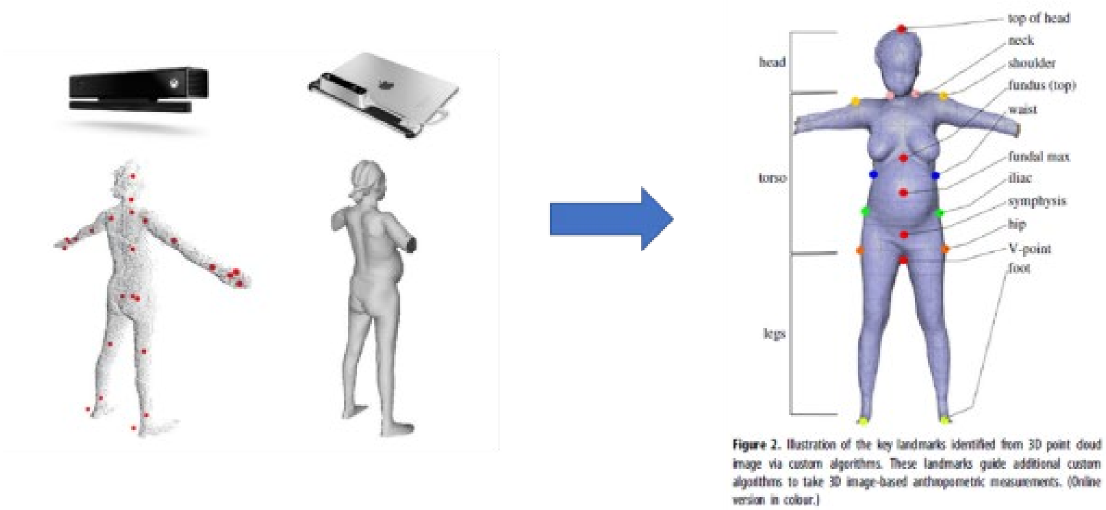

Figure 3 – Visualization of 3D-camera based approach for CPD prediction. The two 3D cameras used in this study are displayed with a sample scan from each tool below the tool. The Kinect camera is on the left, and the Structure camera attached to iPad is on the right. These scans are processed through a custom algorithm that identifies landmarks on the body, which then can be used to calculate measurements that can be used to develop risk scores for CPD. The rightmost figure following the arrow displays a Structure scan with various landmarks identified. Figures are from previous publications from the Gleason lab (Gleason et al., 2018; Tolentino et al., 2019).

These previous studies have demonstrated the feasibility of using 3D camera-based anthropometry to assess risk of CPD-related obstructed labor in Ethiopia, as the resulting risk score of CPD proved more predictive than previous CPD risk scores. Additionally, successful execution of these studies in Ethiopia demonstrated that a 3D camera scanning based tool has strong potential to be acceptable for the intended users of Ethiopian nurses and pregnant mothers, and the intended environment of Ethiopian health care facilities. Once the final CPD risk assessment tool is created, future studies will need to be conducted to further evaluate the feasibility, usability, and acceptability of the tool for all intended users, stakeholders, and environments.

However, one major weakness of the previous studies that the Gleason lab has conducted on this topic is that the measurement approaches were not evaluated for their repeatability. As only one Structure scan, one batch of Kinect scans, and one set of traditional tape measurements were obtained per subject, it was not possible to know if or by how much the measurements obtained through these methods would be different if they were taken by another user, or with another device, or simply at a different time. However, many opportunities for variation could arise. Despite their training, nurses might fail to always obtain traditional anthropometric measurements with the same method, or to always circle and scan the participant with the Structure scanner with the same speed, or to give adequate instructions to stand still and in the correct position to the participants as are scanned with either of the 3D scanners. Participants could introduce variation by standing differently or moving while being measured with any of the tools. Hardware and environmental factors could contribute to variation. Finally, it is also possible that some specific measurements are more difficult to obtain than other measurements, and therefore may have different levels of variation. As the measurements obtained through these methods are eventually to be used in a CPD risk assessment model, in order to prevent the misclassification of participants, it is important that the measurements that are going into that model are as accurate to the actual physiology of the participants as possible. Therefore, there is pressing need to evaluate the variation of the measurements obtained by each of these different approaches: traditional anthropometric measurements, Kinect camera-based measurements, and Structure camera-based measurements. As each of these approaches have their own challenges, none of them are considered a “gold standard”, and therefore comparing “accuracy” cannot be the goal of this study. Rather, the purpose of this work is to evaluate the variation of the various measurements obtained by each method multiple times from the same subjects. Through analysis of scans from both a variability study and longitudinal study, the variation of the 3D camera measurements can be better understood in comparison to traditional anthropometric measurements. Understanding the variation of the measurements obtained from the 3D scans will be critical for the development of a robust CPD risk assessment tool.

CHAPTER 2: METHODOLOGY

Participant recruitment, consent, and eligibility

Protocol Development

All studies involving human subjects in this thesis were approved by the Institutional Review Board (IRB) at Addis Ababa University, College of Health Sciences (Protocol number: 054/15/gyn, approved on 7/17/2019) and the IRB at the Georgia Institute of Technology (Protocol number: H19320). The protocol was developed by Dr. Rudolph Gleason and Elianna Paljug in partnership with Dr. Mahlet Yigeremu and Dr. Sisay Teklu, Ethiopian Obstetrician and Gynecologists who are familiar with the study environment and the participants, and fluent speakers of both English and Amharic, the local language of the participants.

Data Collectors

The five data collectors for this study were Ethiopian nurses from the local community where data collection took place. They were fluent in both English and the local languages of the participants, which included Amharic and at some sites Afan Oromoo. Two of these nurses participated in the previous studies(Gleason et al., 2018; Tolentino et al., 2019) that used 3D cameras, and therefore were only trained on the new elements of this study, while three of the nurses were newly trained for this study. These nurses were selected by the local Ethiopian principal investigators and trained by the investigator in partnership with the nurses who had previous experience on the study. The training manual developed by the investigator for this study is found in the appendix of this document (**Appendix, Training Manual**). As a part of this training, the new nurses observed the experienced nurses for at least one week, and then were supervised by the experienced nurses for at least three weeks before conducting data collection independently.

Participant Recruitment, Consent, and Eligibility

Participants for both the longitudinal and variability studies were recruited as they went to their antenatal check-ups. Women were recruited who were pregnant for the first time, 18 to 40 years of age, had a singleton pregnancy, planned for trial of labor, and planned to deliver in a health facility, in addition to meeting the gestational age requirements by each study. The variability study recruited women presenting at a gestational age 36 weeks or above from Tikur Anbessa Specialized Referral Hospital in Addis Ababa, Ethiopia. The longitudinal study recruited women at a gestational age of 12-24 weeks at initial recruitment from Tikur Anbessa Specialized Referral Hospital, and Girar Health Center in Addis Ababa, Ethiopia.

After a participant had been selected to participate in the study, the participant entered a private examination room. The data collection nurse fully informed the participant of the study in the local language they both understood and obtained written informed consent. The nurse used a questionnaire to record the participant information, including hospital card number, age, and gestational age. The nurse confirmed that the participant satisfies the inclusion/exclusion criteria.

Obtaining Measurements

"Traditional" anthropometric measurements

For both the longitudinal and variability studies, *height* and *weight* were measured with a stadiometer and calibrated scale. *Head circumference, shoulder width, shoulder height, waist height, hip height, waist circumference, hip circumference,* and *belly length* were collected with a tape measurement. For the variability study, the additional measurements of *L5S1 height, symphysis height,* and *V-Point height* were collected with a tape measurement, and *hip width* and *waist width* were measured with an anthropometric caliper. These methods for obtaining these measurements are explained in detail below.

Kinect camera scanning

Following the collection of traditional anthropometric measurements, the participant was then asked to disrobe (except for tight-fitting undergarments) and stand facing the Kinect camera (Kinect V2 sensor, Microsoft, Inc.), with their arms approximately 45-degrees from the ground and feet spread ~50 cm apart (**Figure 4**). The nurse then used the Kinect sensor, connected to a custom-made Kinect acquisition software program running on a laptop, to evaluate the participant's position within the Kinect frame. The Kinect platform outputs not only point clouds, but also "Kinect joints" which have been identified by the Kinect platform itself. The custom Kinect acquisition software uses these Kinect joint outputs, which are indicated by red dots in the figure, to calculate if the participant is positioned correct. This software was developed for previous studies of the Gleason Lab, as was tested for adequate performance throughout its use in these studies ((Gleason et al., 2018; Tolentino et al., 2019). The software developers chose to have this software take not just one scan, but 20 scans in rapid succession, so that more samples would be available for the eventual defining of measurements from these scans. The nurse used the software to collect a series of 20 Kinect 3D scans from the anterior view, then the participant turned to face their back to the camera, and 20 scans were taken from the posterior view. The nurse then saved these files onto the laptop as directed on the data collection sheets, following the designated naming scheme.

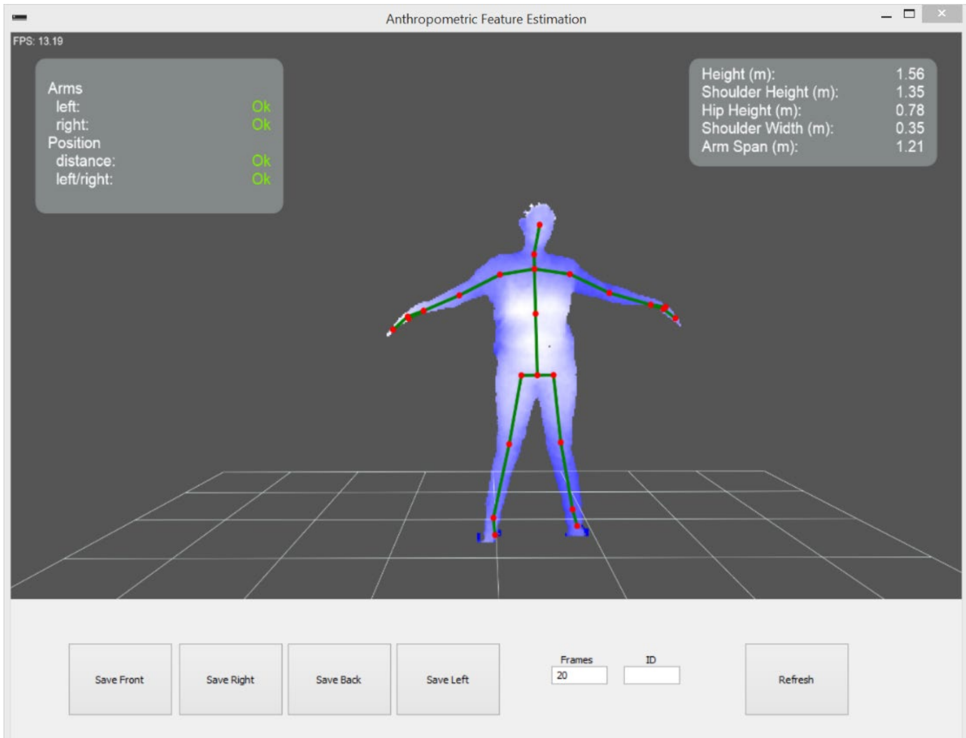

Figure 4 – Visualization of Kinect Scanning.
Screen Capture of Kinect "Anthropometric Feature Estimation" software that is used to collect Kinect scans. The Kinect platform calculates the locations of various skeletal landmarks, which are indicated by the red dots, and the custom acquisition software utilizes these to evaluate the position of the participant. The investigator is posing as a participant here with legs and arms in the proper position for optimal scan quality, as indicated by the "Ok" indicators at the top left panel. This figure is from the training manual used to train the nurse data collectors, which is found in its entirety in the appendix.

Structure camera scanning

Following the Kinect scanning, a Structure 3D camera (Occipital, Inc.) was used to collect a 3D point-cloud image of the participant (**Figure 5**). The software used for acquisition was the default software created by Occipital for scanning, but had been modified to make the region of scanning a rectangular prism instead of a cube, to better fit the human participants. This software was developed and used in previous versions of the Gleason Lab's work (Tolentino et al., 2019). To prepare for scanning, the nurse placed a bedsheet over the floor to prevent reflection from impacting the scan.

A **B**

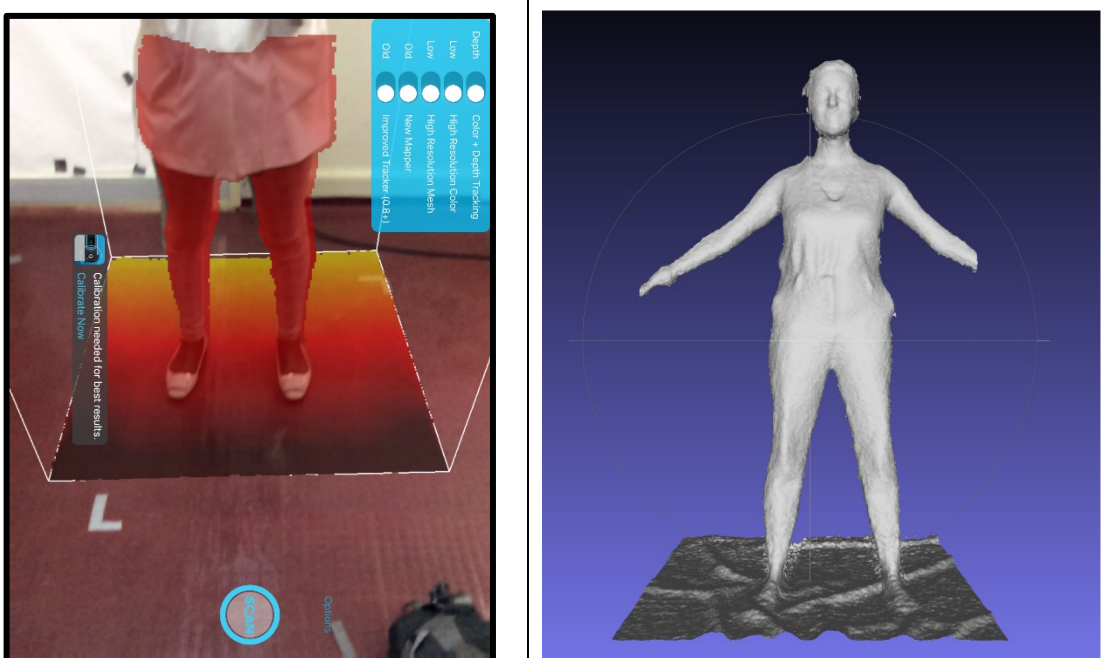

Figure 5 – Visualization of Structure Scanning.
Panel A shows a screen capture from Structure Scanner software on the iPad, with a nurse data collector posing as a participant to demonstrate proper positioning of the participant in the center of the scanning region. Panel B shows the point cloud generated from scanning with the Structure Scanner, visualized on a laptop with the MeshLab software. This scan is also of one of the participants posing as a participant, demonstrating the proper arm and leg positioning. These figures are from the training manual used to train the nurse data collectors, which is found in its entirety in the appendix.

To obtain the scan, the participant was asked to remain in the same position as they had been for the Kinect scanning, with their arms approximately 45-degrees from the ground and feet spread ~50 cm apart. The participant remained stationary as the nurse moved the Structure camera around the participant, and the software stitched together the various depth information it received as the nurse moved. After the nurse had entirely circled the participant, the software stitched this information to obtain a 3D model of the participant as a point cloud. Following the collection of the 3D scan, the nurse then named the scan as directed in the data collection sheets, following the designated naming scheme.

Data processing

Each participant's data was then collected by the Georgia Tech based study team and processed accordingly. Anthropometrics measurements were entered from the paper questionnaires into a custom-made KoboToolbox™ (Harvard Humanitarian Initiative, Cambridge MA) data entry system, and double entry was conducted to clean the data. The Structure and Kinect scans were each processed through algorithms in MATLAB, R2020b™ (MathWorks, Natick MA) that generated a spreadsheet of measurements from each scan. The Structure scan algorithms output 45 unique measurements, and the Kinect scan algorithm outputs 89 unique measurements. Following the obtaining of measurements from all scans, the data was processed to generate spreadsheets in Excel™ (Microsoft, Redmond WA) containing each participant's Anthropometric, Kinect, and Structure measurements. To add further clarification, the measurements from the 3D scans were entirely calculated by the Georgia Tech team's algorithm, and the nurse data collectors did not see, verify, approve, or correct these measurements.

Measurement Descriptions

Similar measurements to those obtained by the traditional anthropometric approach (referred to as "Anthropometric" or "Anthro" measurements for the rest of this document) were also obtained by the algorithm which processed the Structure and Kinect scans, although the approach for identifying these measurements sometimes differed due to the capabilities of the algorithm and features of the scan. The following section describes the measurements obtained by each modality.

Anthropometric measurements

The measurements obtained through traditional anthropometric tape measurement are described in the following text and displayed in **Figure 6.**

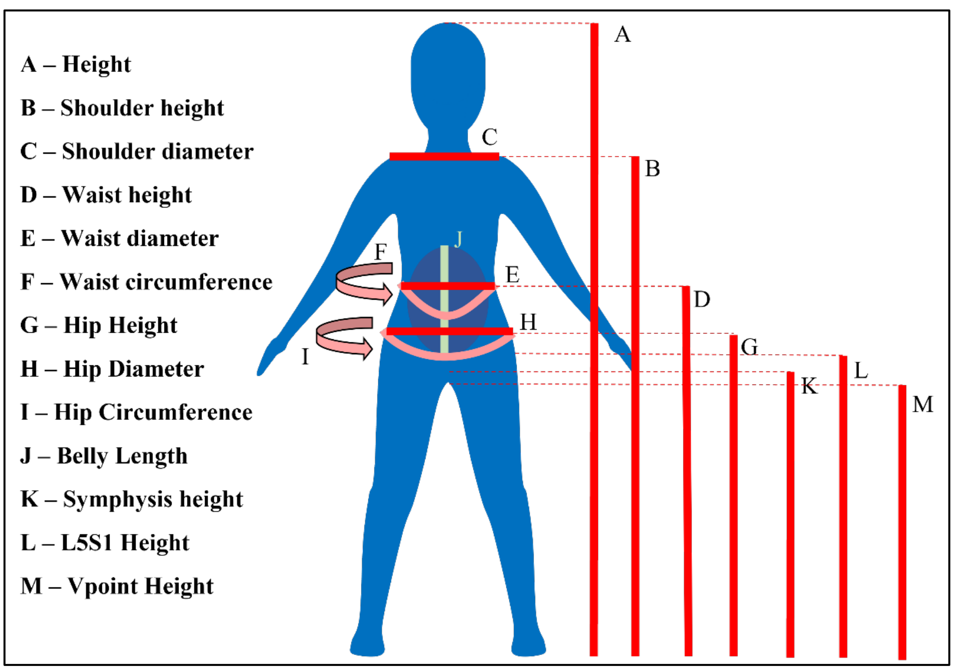

Figure 6 – Anthropometric measurements.
This diagram was created from diagrams used in training the nurses on how to properly obtain the measurements. Heights and widths are indicated in red, circumferences in pink, and belly length in light green. The key on the left side indicates the names for each of the measurements.

Height

A length board was used for this measurement. The nurse asked the participant to stand with her ankles against the back of the length board and lowered the board to touch the top of the participant's head and recorded the height.

Shoulder height and Shoulder width

The nurse identified the shoulder points on each side as the ends of the clavicle bone. To measure *Shoulder height,* after this point was identified, the nurse asked the participant to hold the tape measure at this spot on one side. The nurse then stretched the tape measure to the floor and obtained the measurement where the tape measure reached the floor. To measure *Shoulder width,* the nurse placed the tape measure end at one of these points and stretched the tape measure along the back of the participant to the other shoulder point on the other side and obtains the measurement at this point.

Waist height, Waist width, and Waist circumference

The waist points were identified as the narrowest parts of torso along the frontal plane, on the left and right side of the body. To measure *Waist height,* the participant was asked to hold the tape measure at one of these points on one side of the body. The nurse then stretched the tape measure to the floor and obtained the measurement where the tape measure reached the floor. To measure *Waist width,* the nurse placed an anthropometric caliper at these points and used it measure the width. To measure *Waist circumference,* the nurse places one end of the tape measure at this one of these points and wrapped it around the participant's body along a plane horizontal to the floor and obtained the measurement where the tape measure met the other end.

Hip height, Hip width, and Hip circumference.

The hip point was identified as the widest part of hips along the frontal plane, on either the left or right side of the body. The same procedure of measuring *Waist height, Waist height,* and *Waist circumference* was repeated, but instead using these hip points to define *Hip height, Hip width,* and *Hip circumference.*

Belly length

The nurse palpates for the location of the participant's sternum, and then places one end of the tape measure at the participant's sternum, stretches the tape measure vertically down to the bottom of the belly's curve, and obtains the measurement at this location.

For the following height measurements, the nurse identified the point as indicated for each measurement. After this point was identified, the nurse asked the participant to hold the tape measure at this spot. The nurse then stretched the tape measure to the floor and obtained the measurement where the tape measure reached the floor.

Symphysis height

The symphysis point was approximated by the nurses to at the approximate height of the symphysis bone, on the anterior surface of the body.

L5S1 height

The L5S1 point was approximated by the nurses to at the approximate height of the L5S1 bone, on the posterior surface of the body.

VPoint height

The VPoint was identified by the nurses to be at the height of the participant's perinium, but approximately three centimeters in front of the participant's body for participant's comfort.

Structure measurements

The Structure 3D camera-based measurements are described in the following text as they were defined in the custom-made MATLAB algorithm. Several of the landmarks and circumference used to obtain these measurements are in **Figure 7**. Before measurements were obtained, the Structure scan was pre-processed to identify the floor, and then realigned so that the bottom of the participant's feet was along the y=0 axis, the back of their heels along the z=0 axis, and the fingertips of their right hands were along the x=0 axis.

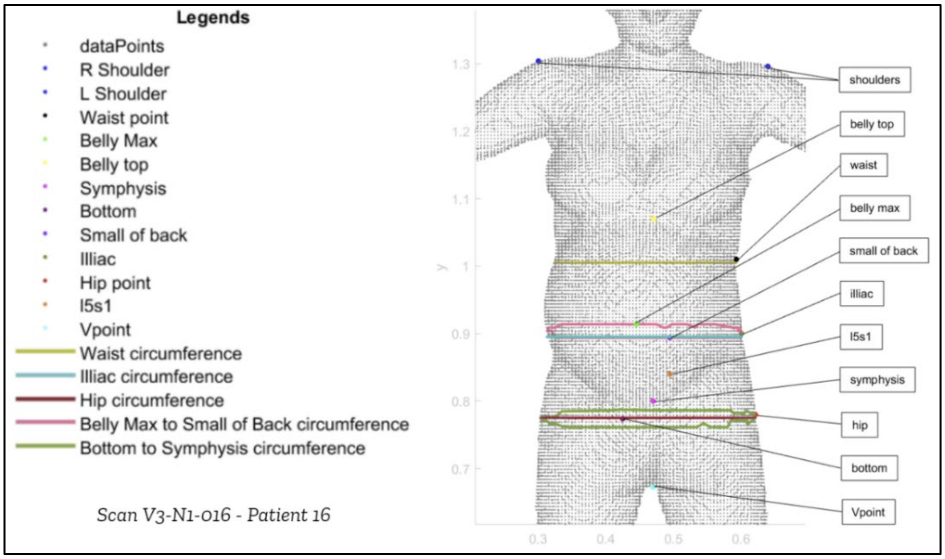

Figure 7 – Structure 3D camera-based measurements.
A Structure scan of a participant from the Variability Study is displayed, magnified to focus on the torso region. Several of the landmarks indicated in the legend on the right-hand panel are used in the measurements described in the text, and several circumferences are drawn on the body.

Height

The height was obtained by the max Y value of the point cloud.

Shoulder height and Shoulder width

The shoulder point was identified by first identifying the armpit. This was found by rotating the point cloud, finding the "bottom border" of the point cloud (points with the lowest Y values for every X value), and identifying the point with the maximum Y value as the armpit. The point cloud was then rotated back to vertical, and the shoulder point was identified by finding the "top border" of the point cloud (points with the highest Y values for every X value) and identifying the point along this border that has the most similar X value to the armpit. The process is repeated for both shoulders. The *Shoulder height* was defined as the average Y value of these shoulder points, and *Shoulder width* was defined as the distance in the X direction between these shoulder points.

VPoint height

The VPoint was identified by first identifying the participant's ankles as the minimum values along the right and left side of the participant. The bottom border of the body was then identified and restricted to only include points with X values between those of the ankle points. The Vpoint was identified as the point with the maximum Y value within this border.

Waist height, Waist width, and Waist circumference

The waist was defined as the narrowest part of the torso. The torso was defined as all points that are not the legs (all points inferior to the Vpoint), the neck and head (all points superior to the shoulders), and the arms (all points lateral to the shoulders). The waist point was identified by obtaining the XY plane "borders" on the left and right side of the torso, (identified as the highest X and lowest X values, respectively, for each Y value). From these borders, the points that were at the top 30% of the torso or inferior to the belly max point were removed to isolate the mid torso. The waist point was identified as the point along the left border where the X distance between the left and right border was the smallest. The *Waist height* is defined as the Y value of this waist point. Next, waist region is identified as a region 1 cm tall that was centered at the Y value of the waist point. The *Waist width* was defined as the maximum range of values within this region, and the *Waist circumference* was defined by finding the perimeter of a polygon fitted to the convex hull of this region.

Hip height, Hip width, and Hip circumference.

The hip measurements were similar to the waist measurements, but instead were at the widest part of the torso. The points that had y-values greater than the belly max point or less than the buttocks point was removed to isolate the lower torso. Within this region, the hip point was identified as the point along the left border where the X distance between the left and right border was the largest. The *Hip height* was defined as the Y value of this hip point, and a hip region 1 cm tall centered around this point was identified to obtain *Hip width* as the maximum range of values within this region, and *Hip circumference* as the perimeter of a polygon fitted to the convex hull of this region.

Symphysis height

The symphysis point indicates the bottom of the protrusion of the belly. It was defined using the belly max point, which is the point within the torso where the Z value is the largest. The symphysis point was defined as the point along the ZY plane "borders" on the front and back of the torso, and below the belly max point, where the slope of the values has the sharpest change. The *Symphysis height* was defined as the Y value of the symphysis point.

Belly length

The belly length measurement uses both the symphysis point and the belly top point. The belly top point, which approximates the sternum, was identified by finding the ZY "borders" on the front and back of the torso and identified where the Z value slope has the sharpest change, to indicate the top of the protrusion of the belly. *Belly length* was calculated by using the distance formula on the front border points between the belly top point and the symphysis point.

L5S1 height

The L5S1 point was found by isolating the points on the back of the subject which are below the waist and above the bottom. Within this region, value with the maximum Z value was defined as the small of back point. The L5S1 point was approximated as having the X value of this small of back point, the Y value of 6 centimeters below the hip point, and the Z value of the closest point along the back region with the designated Y value. *L5S1 height* was defined as the Y value of this L5S1 point.

Kinect measurements

Several of the Kinect 3D camera-based measurements were identified following similar methods to the Structure 3D camera-based measurements, but others had differences. As mentioned previously, the Kinect method obtains 20 scans of the front of the body (referred to as the "front scan") and 20 scans of the back of the body (referred to as the "back scan"). In addition to outputting 3D point clouds from these scans, the Kinect software itself also outputs several "Kinect joints" from each scan, which already pre-define the XYZ location of certain landmarks (**Figure 8**). In developing the Kinect algorithm, different versions of the measurements were defined by using these Kinect joints and by using the 3D point cloud, and by using the front and back scans.

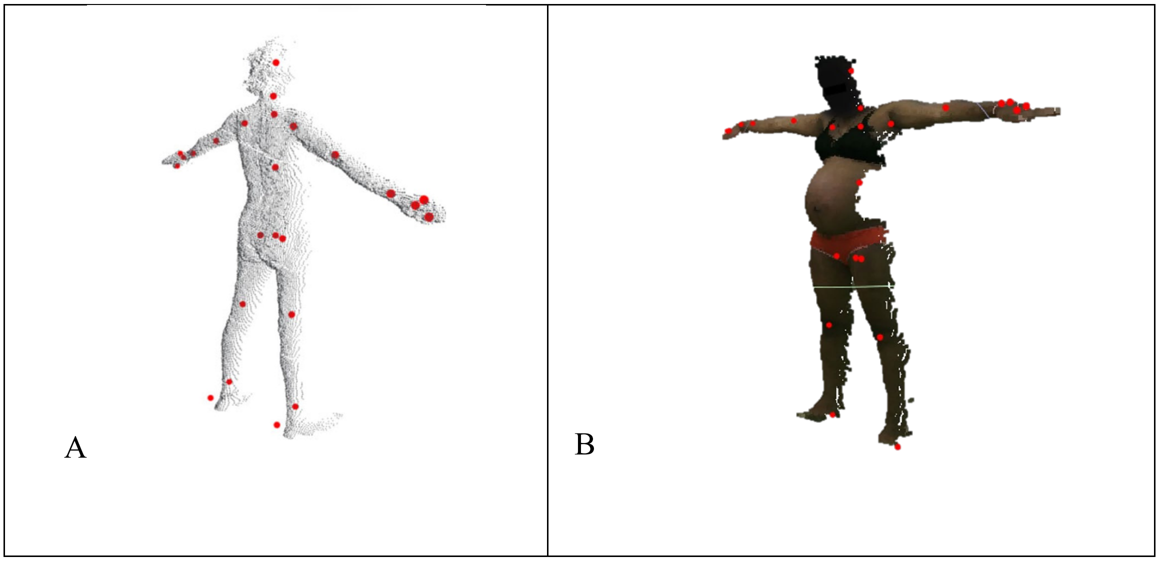

Figure 8 – Visualization of predetermined Kinect joints used for several Kinect 3D camera-based measurements.
Panel A indicates Kinect joints from a back scan, and panel B indicates Kinect joints from a front scan. These figures are taken from the Gleason Lab's previous publications on this work. Measurements were defined from both views, and the measurement with the least variation was chosen for subsequent analysis.
(Gleason et al., 2018; Tolentino et al., 2019)

For example, there were four different versions of the measurement *hip height*: one from the Kinect joints of the front scan, one from the Kinect joints of the back scan, one from the point clouds of the front scan, and one from the point clouds of the back scan. All of these measurements were calculated for all 40 of the scans obtained per subject, and then the median of each measurement was kept as the final measurement for that subject. An additional level of selection was done for this study to choose just one of the various versions of the measurements, as described by the four versions of *hip height previously.* The ultimate versions described below are the measurements which had the best results in the subsequent analysis, and are used throughout the rest of this study.

Unlike the Structure point clouds, the Kinect point clouds do not contain the floor, pre-processing only consisted of aligning the point cloud so that the participant's feet were along the y=0 axis, the back of their heels along the z=0 axis, and the fingertips of their right hands were along the x=0 axis.

Height

The *Height* measurement was defined as the Y value of the predefined head Kinect joint from the front scan.

Shoulder height and Shoulder width

The shoulder measurements were defined using the predefined shoulder Kinect joints from the front scan. The *Shoulder width* was defined as the difference in X values between the right and left shoulder joints, and the *Shoulder height* was the mean of the heights of the right and left shoulder joints.

VPoint height

The *Vpoint height* method was identical to that for Structure and uses the front scan.

Waist height, Waist width

The *Waist height* method was identical to that for Structure and uses the front scan. The *Waist width* used the back scan and had method similar to that for Structure in that it uses the side borders, but it involved an additional level of smoothing of these borders, and then defined *Waist width* as the minimum difference between the right and left boundary.

Hip height, Hip width, and Hip circumference.

The *Hip height* measurement was defined as the mean of the heights of the right and left hip Kinect joints from the back scan, and the *Hip width* measurement was defined as the difference in X values between the right and left hip Kinect joints on the front scan.

Symphysis height

The *Symphysis height* method was identical to that for Structure and used the front scan.

Belly length

The *Belly length* method was identical to that for Structure and used the front scan.

L5S1 height

The *L5S1 height* method was identical to that for Structure, but it used the front scan, and therefore indicated the approximation of the L5S1 location on the front of the body instead of on the back.

Variability Study - Variation of 3D Image & Traditional Anthropometry on Pregnant Women

Variability study data collection

For the variability study, this procedure of obtaining traditional anthropometric measurements, a batch of twenty anterior and twenty posterior Kinect scans, and a Structure scan, was repeated three times for each participant, one after another during the same visit. For each repetition, a different nurse collected the measurements or the scans, with each nurse using a different Kinect camera and different Structure camera. Thus, for each participant, the team obtained three sets of anthropometric measurements, three sets of Kinect scans, and three sets of structure scans, each collected by a different nurse, and using different equipment.

Standard Deviation and Mean Calculations

The Structure and Kinect scans were analyzed by the investigator's custom MATLAB code to obtain the 3D-camera anthropometric measurements, as described above. Several measurements were obtained by all three modalities, and therefore are able to be compared directly. The measurements obtained by all three modalities are grouped into heights: *height, shoulder height, waist height, hip height, L5S1 height, symphysis height,* and *vpoint height,* and widths: *shoulder width, waist width, hip width* and *external conjugate.* The circumference measurements of *waist circumference* and *hip circumference* were only obtained by traditional anthropometry and Structure 3D camera-based measurements, as these require a complete 3D views of the participant, but the half circumference of *belly length* was taken by all modalities.

To illustrate how these values were analyzed, the values obtained from one participant's *height* measurements (participant 8) by the Structure camera were 162.83 cm, 163.42 cm, and 163.34 cm (**Figure 9**), which had a mean value of 163.12 cm and a standard deviation of 0.29 cm. The measured height from the Kinect camera were 150.32 cm, 151.43 cm, and 152.81 cm (mean = 151.52 cm, s.d. = 1.24 cm) and the measured height using the length board were 162.0 cm, 163.0 cm, and 163.1 cm (mean = 162.7 cm, s.d. = 0.61 cm). As evidenced by this analysis, the Structure measurements were closer to the length board measurements, with the average being within 1 cm of each other, and also had a more similar range of values to the traditional anthropometric measurement, with both having a range of nearly 1 cm. However, the Kinect measurements were both lower and had a wider range than the traditional anthropometric measurements.

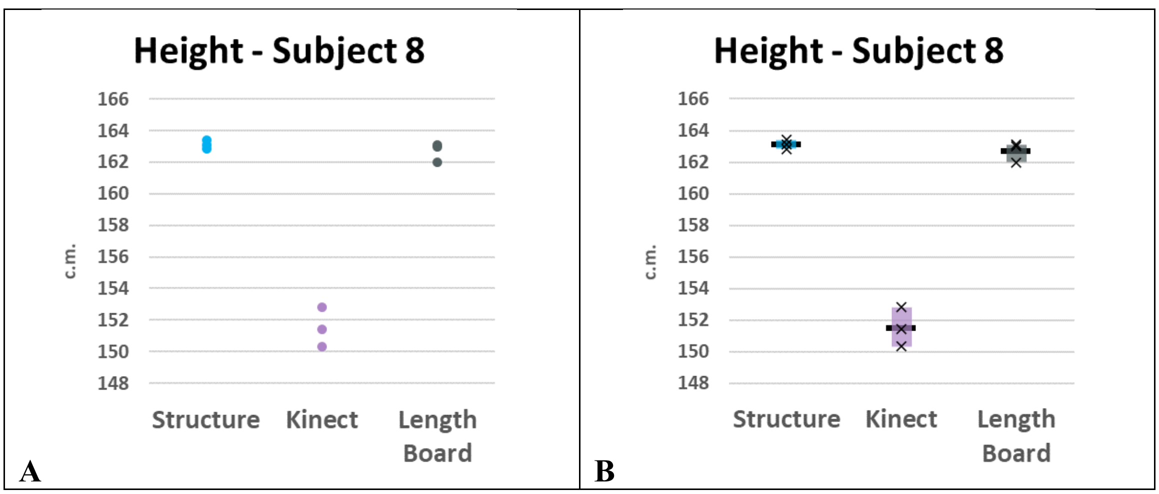

Figure 9 – Demonstration of nine measurements obtained from representative participants, with three measurements obtained from Structure, three from Kinect, and three from the Length board.
These measurements are stated as points in panel A, and the average of the numbers are indicated by black bars.

This is most likely due to issues with the Kinect scans, which often do not fully scan the feet of the participant, making height difficult to calculate. For each participant, the means and ranges of each measurement obtained with each modality were calculated , and the standard deviation of the measurements obtained with each modality. For example, for participant 8's *height* measurement, the investigator obtained the range indicated by the bar in panel B, the mean indicated by the black line in panel B, and the standard deviation of the values obtained from each modality.

Variation analysis

Variation was defined as the standard deviation between measurements obtained from the same modality. To illustrate, for subject 8, the Kinect measurements taken by three different nurses showed a larger standard deviation, compared to the standard deviation from Structure and from the Length Board measurements. To determine whether Kinect does have less variation (i.e., has a higher deviation of values across multiple measurements) than Structure and traditional anthropometry, it is necessary to perform this inter-user variability study across multiple subjects and perform statistical analysis comparing the standard deviation of each modality across the multiple subjects. Thus, for each measurement and each modality, one standard deviation value was calculated per subject. The statistical significance of the differences between the variation (i.e., the standard deviation) was calculated by the Kruskal-Wallis one way analysis of variance test through pairwise multiple comparison tests. Statistical significance was defined as having a p value of less than 0.05. These standard deviations are displayed as box plots comparing the values obtained for each modality, grouping together the various height measurements, width measurements, and circumference measurements. The median, interquartile range, and number of outliers for each measurement, for each modality was reported, in addition to the p values obtained when comparing the Structure and Kinect measurements to the Anthropometric measurements, and when comparing the Structure and Kinect measurements to each other.

Variation analysis with outlier removal

To analyze how the presence of outliers influenced the variation analysis, this analysis was repeated with the adjustment of removing outliers. The justification for exploring the removal of outliers is because the reason the outliers are present in this dataset will likely be eliminated once the tool is further developed. For traditional anthropometric measurements, the current system does not contain any checks for mistakes. Although data cleaning is done to ensure that the data entry is accurate to what he nurses handwrite on the questionnaire, if the nurse incorrectly wrote down a measurement, there is no current step for this to be checked, and this mistake will make its way to the final dataset. In the future, the eventual tool would not be a paper form, but instead a digital platform that uses the traditional anthropometric measurements for the first step of a triaged CPD risk score(Tolentino et al., 2019). This tool would have a software check to ensure the values inputted by the nurse are physiologically plausible. For example, if the nurse gave a height value less than a shoulder height value, it would tell the nurse that she made a mistake and asked her to review the input and make an appropriate change. This type of system would most likely eliminate the presence of the outliers that are present within the traditional anthropometric data in this dataset, as well as the longitudinal dataset which will be discussed later. As this system was not used in data collection, removal of outliers that would be found by this system is appropriate.

For the 3D camera-based approaches, outliers are present because either the scan has an issue in the region of the landmark needed for that measurement, or because the algorithm did not properly obtained the measurement from the scan. Although the nurses have been well trained to obtain high quality scans, it is possible that the nurse data collector or the pregnant mother participant could contribute to a scan quality issue. Future versions of both the Kinect and Structure 3D camera-based approaches could address this possibility by having quality checks that ensure that the scan is of appropriate quality before the nurse finishes data collection. Although the algorithm used to obtain measurements in this study has been developed and tested through the collection of hundreds of scans of Ethiopian pregnant women, given that pregnant women come in all shapes and sizes, it is possible that a woman could participate in the study who has a body shape that is different than all previous participants, and therefore the algorithm does not properly obtain the measurements from her. Future work on this algorithm will continue as data collection grows, so that the chance of this reason for error is reduced. For these reasons the removal of outliers from the 3D camera-based tools is also rationalized.

The reasoning for not removing outliers for all analysis is because the researchers thought it is still valuable to be able to compare the numbers of outliers in each modality, which further highlight the needs for improvements to be made in each approach. However, the advantage of removing the outliers is that the modalities are able to be compared in a way that is more similar to how they eventually might be when the approaches are fully developed.

As is customary for analysis through box plots since their invention by mathematician John Tukey, outliers were identified as subjects who for a specific measurement had a standard deviation value more than 1.5 interquartile ranges above the

75th quartile. However, the process of removing outliers could not be as simple as simply removing all the standard deviation values that fit these criteria, as the goal of this analysis is to compare the results between modalities, which requires the same subjects to be in each comparative group. For example, of the 17 subjects included in Variability Analysis, 3 of the subjects had outliers within their Kinect *shoulder height* measurement. If these 3 subjects were only removed from Kinect, we would be comparing the values of 17 subjects' traditional anthropometric measurements, 17 subjects structure measurements, and only 14 subjects Kinect measurements. The difference in sample size per group would prohibit a fair comparison. Therefore, the 3 subjects who had outliers in their Kinect *shoulder height* measurements also had their traditional anthropometric and Structure *shoulder height* measurements removed. However, those 3 subjects were not thrown out of the entire analysis for all measurements, because it is very feasible that the issues with the Kinect measurements for those 3 subjects are not present in the rest of the scan. For example, if the participants moved their arms during data acquisition, the shoulder measurements are likely to be negatively impacted, but the torso measurements will be not be impacted. Therefore, each measurement was evaluated separately for this removal process. The statistical evaluations to compare the variation of groups was repeated.

Average analysis

To analyze differences in how the measurements were defined by each modality, the average value of each measurement across trials was calculated for each modality, which is the value indicated by the black bar in **Figure 9**. These values were calculated for each measurement, separated by modality, and grouping together heights, widths, and circumferences. These values were also compared using the Kruskal-Wallis one-way analysis of variance test through pairwise multiple comparison tests, with statistical significance defined as a p value of less than .05. The median, interquartile range, number of outliers, and p values were also reported. Outliers were identified as values more than 1.5 interquartile ranges above the 75^{th} quartile or below the 25^{th} quartile.

Longitudinal Study - Variation of 3D Image & Traditional Anthropometry on Pregnant Women

Longitudinal study data collection

For the longitudinal study, this procedure of obtaining traditional anthropometric measurements, Kinect scans, and a Structure scan, was only done once for each participant per visit. Gestation was divided into four periods, with period 1 being 12-19 weeks, period 2 being 20-24 weeks, period 3 being 28-32 weeks, and period 4 being 36-42 weeks. These periods follow the guidelines for when women in Ethiopia should be going to a health center or hospital for their antenatal care visits. Following recruitment within any timepoint between the start of period 1 and the end of period 2, women were then asked to come back for the study when they returned for their antenatal care visits, during the next periods. Therefore, women could participate up to four times if they were enrolled in the study at the first period, and up to three times if they were enrolled in the study at the second period.

Standard Deviation Calculations

Just as for the Variability Study, the Structure and Kinect scans were processed through the investigator's custom MATLAB software to obtain various measurements, as described previously. Although not all the Anthropometric measurements that were measured in the Variability Study were obtained in the Longitudinal Study, these measurements (*L5S1 height, symphysis height, Vpoint height, waist width, hip width*) can still be grouped together with just their Structure and Kinect measurements. Analysis of the measurements was conducted in MATLAB, R2020b. For each modality, the measurements obtained from the same subject over time were grouped together, and the standard deviation was calculated across visits. Subjects were only included who came to three or four visits, and therefore had three or four datasets to compare.

Variation Analysis

The longitudinal study measurements can be used to analyze measurement variation by comparing the measurements obtained from the same subject in different visits. Only the measurements that are expected to not change over time (namely, *height, shoulder height, waist height, hip height, L5S1 height, symphysis height, Vpoint height, waist width, hip width, shoulder width, hip circumference)* are analyzed similarly to the measurements in the Variability study, with a lower standard deviation between these measurements indicating that the modality has less variation when obtaining these measurements.

Variation Analysis with outlier removal

Similarly, to the Variability Study analysis, to analyze how the presence of outliers influenced the variation analysis, the analysis was repeated with the adjustment of removing outliers. Outliers were again identified as values more than 1.5 interquartile ranges above the 75^{th} quartile, and similarly to the Variability Study, participants who had an outlier in one measurement in one modality had measurements removed for all modalities for that measurement.

Longitudinal Analysis

In order to further understand how the measurements from each modality changed over time, as they were collected at different visits, the measurements were visually analyzed by plotting same measurement obtained by different participants over time, with the same participant indicated by the same color lines. The data in this analysis is postadjustment, with outliers already removed, and as discussed, the outliers removed varies per measurement. Therefore, the participants included in each panel do vary, but the participants included within a panel's various modalities of the same measurements are the same. The y-axis of these graphs is defined by the average value obtained for these measurements in previous studies, subtracting and adding five times the standard deviation for that measurement from that study. The x-data for these points is the gestational age of the participant's baby at the time of their visit.

CHAPTER 3 : RESULTS

Variability Study - Variation of 3D Image & Traditional Anthropometry

Variation analysis

For the Variability Study, 17 subjects were included. Measurements obtained from the Structure modality are generally have similar or less variation than those obtained by traditional Anthropometric measurements, and for some measurements the Structure measurements have less variation than their corresponding Kinect measurements (**Figure 10, Table 1)**. Specifically, the standard deviations of Structure measurements showed less variation compared to traditional anthropometric measurements for *shoulder height, waist height, hip height, VPoint height, waist width,* and *hip width,* showed no difference in variation for *height, L5S1 height, symphysis height, shoulder width, external conjugate, waist circumference,* and *hip circumference,* and showed larger variation for *belly length*. Nominal comparison of the outliers in each technique may indicate that the Structure approach may be less prone to outliers than traditional anthropometric measurement approach (10 Structure outliers vs 13 Anthro outliers). These results show the lower variation of the Structure method of obtaining measurements, and its potential improved performance in comparison to the Anthropometric measurement approach.

For the Kinect approach, of *hip height, VPoint height, shoulder width, waist width,* and *hip width* showed lower variation in comparison to traditional anthropometric measurements, *height, shoulder height, waist height, L5S1 height, symphysis height,* and *belly length* showed no difference in variation in comparison to traditional anthropometric measurements. In comparison of the Kinect measurements to

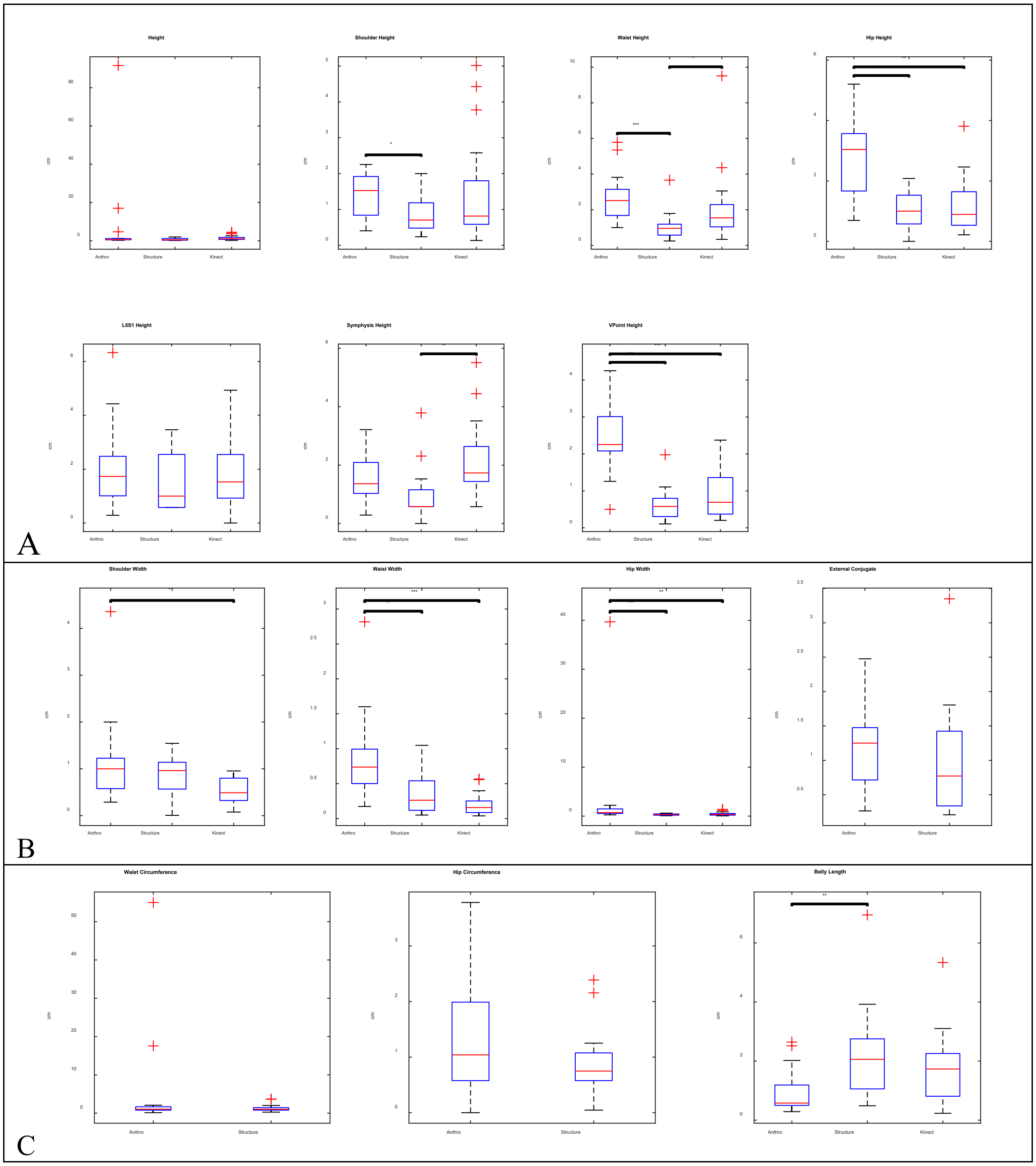

Figure 10 – Variability Study – Variation Analysis

*Box plot of standard deviation (cm) for each comparative measurement from each modality for all subjects (n=17), with heights in panel A, widths in B, and circumferences in C. Statistical significance was performed by Kruskal-Wallis one way analysis of variance in MATLAB. * indicates* $p \leq .05$, *** indicates* $p \leq .01$, and **** indicates* $p \leq .001$. *Points indicated by the red "+" are 1.5 interquartile ranges above the 75th percentile or below the 25th percentile, although only those above the 75th quartile are considered outliers in Table 1.*

Table 1 – Variability Study – Variation Analysis

Analysis of standard deviations across measurements, indicating for each measurement, for all each modality, the median (cm), interquartile range (cm) (25^th quartile and 75^th quartile), and the number of outliers above the 75^th quartile. Statistical significance was performed by Kruskal-Wallis one way analysis of variance in MATLAB. The P-values are stated for the comparison of Structure and Kinect measurements to the Anthropometric measurements, and for the comparison of the Structure and Kinect measurements to each other.

Variability Study Results - Variation Analysis of standard deviations for each subject *(n=17)*						
					p-value	
	Measurements	**Modality**	**Median (IQR)** ***cm***	**Outliers**	**to Anthro**	**Kinect to Structure**
Heights	**Height**	Anthro	0.58 (0.48 - 1.14)	3		
		Structure	0.48 (0.29 - 1.15)	0	0.734	
		Kinect	1.02 (0.72 - 1.74)	3	0.374	0.092
	Shoulder Height	Anthro	1.53 (0.84 - 1.92)	0		
		Structure	0.71 (0.48 - 1.19)	0	0.037	
		Kinect	0.82 (0.59 - 1.80)	3	0.313	0.574
	Waist Height	Anthro	2.52 (1.68 - 3.15)	2		
		Structure	0.96 (0.58 - 1.19)	1	<.001	
		Kinect	1.55 (1.04 - 2.29)	2	0.190	0.033
	Hip Height	Anthro	3.04 (1.67 - 3.57)	0		
		Structure	1.00 (0.58 - 1.53)	0	0.001	
		Kinect	0.89 (0.53 - 1.64)	1	0.002	0.996
	L5S1 Height	Anthro	1.73 (1.01 - 2.48)	1		
		Structure	1.00 (0.58 - 2.55)	0	0.431	
		Kinect	1.53 (0.92 - 2.55)	0	0.955	0.610
	Symphysis Height	Anthro	1.36 (1.03 - 2.09)	0		
		Structure	0.58 (0.58 - 1.15)	2	0.051	
		Kinect	1.73 (1.44 - 2.64)	2	0.428	0.001
	VPoint Height	Anthro	2.25 (2.08 - 3.01)	0		
		Structure	0.58 (0.30 - 0.80)	1	<.001	
		Kinect	0.69 (0.37 - 1.36)	0	<.001	0.633
Widths	**Shoulder Width**	Anthro	1.00 (0.58 - 1.23)	1		
		Structure	0.96 (0.57 - 1.14)	0	0.794	
		Kinect	0.49 (0.32 - 0.80)	0	0.030	0.141
	Waist Width	Anthro	0.74 (0.50 - 0.99)	1		
		Structure	0.26 (0.12 - 0.54)	0	0.005	
		Kinect	0.16 (0.09 - 0.25)	2	<.001	0.374
	Hip Width	Anthro	0.72 (0.54 - 1.47)	1		
		Structure	0.30 (0.19 - 0.44)	0	<.001	
		Kinect	0.33 (0.20 - 0.53)	2	0.001	0.826
	External Conjugate	Anthro	1.25 (0.71 - 1.48)	0		
		Structure	0.77 (0.34 - 1.42)	1	0.221	
Circumferences	**Waist Circumference**	Anthro	1.04 (0.77 - 1.67)	2		
		Structure	1.01 (0.78 - 1.43)	2	0.718	
	Hip Circumference	Anthro	1.04 (0.58 - 1.99)	0		
		Structure	0.75 (0.58 - 1.08)	2	0.196	
	Belly Length	Anthro	0.58 (0.50 - 1.19)	2		
		Structure	2.06 (1.06 - 2.75)	1	0.006	
		Kinect	1.73 (0.81 - 2.26)	1	0.072	0.000

to the Structure measurements, *waist height* and *symphysis height* had higher variation compared to their Structure counterparts.

Comparing these results to that of Structure, for the six Structure measurements that had lower variation compared to the traditional anthropometry measurements (*shoulder height, waist height, hip height, VPoint height, waist width,* and *hip width),* the corresponding Kinect measurements also had lower variation compared to the Anthropometric measurements for *hip height, Vpoint height, waist width,* and *hip width,* but did not have any difference in variation in comparison to the Anthropometric measurements for the measurements of *shoulder height* and *waist height* although the Kinect measurement of *waist height* had higher variation than its Structure counterpart. For the four Structure measurements that had no change in variation in comparison to the traditional anthropometry method, and that also had corresponding Kinect measurements (*height, L5S1 height, symphysis height,* and *shoulder width*), the Kinect measurements also had no change for all measurements except *shoulder width,* which had lower variation, although the measurement of *symphysis height* had higher variation than its Structure counterpart. For the Structure measurement that performed worse than the anthropometric measurement, *belly length*, the Kinect measurement showed no difference. Nominal comparison of the number of total outliers per method for measurements that were compared by all three methods (Anthro = 11, Structure = 6, Kinect = 16) indicates that the Kinect method may be more prone to outliers than both the traditional anthropometry and Structure methods. These results indicate that while the Kinect method sometimes obtained results with similar or lower variation to those obtained by the traditional anthropometry or Structure methods, it may not have as much improvement in variation the Structure method.

Variation analysis with outlier removal

When the outliers from the standard deviation measurements are removed from the variation analysis, the conclusions generally remain the same. (**Figure 11, Table 2**). The removal of outliers from the Structure measurement of *symphysis height* changes the measurement of from having no difference to traditional anthropometry to having lower variation. The removal of Anthropometric outliers from the *shoulder width* measurement makes the Kinect *shoulder width* measurement change from having lower variation in comparison to traditional anthropometry to having no change, and the removal of traditional anthropometry and Kinect outliers from *belly length* makes the Kinect measurement change from having no difference in comparison to traditional anthropometry to having higher variation. As the outlier removal process removes a subject's measurements from all modalities for that measurement, removal of the three outliers from Kinect's *shoulder height* measurements removes three subjects from traditional anthropometry and Structure as well, which changes the Structure measurement from having lower variation in comparison to having no change in comparison to traditional anthropometry. This result indicates a weakness of the outlier removal method. In addition to these changes, this analysis allows for a clearer visualization of the differences between standard deviations for each modality, especially for measurements that had extreme outliers in the unadjusted analysis, such as *height, hip height,* and *waist circumference.*

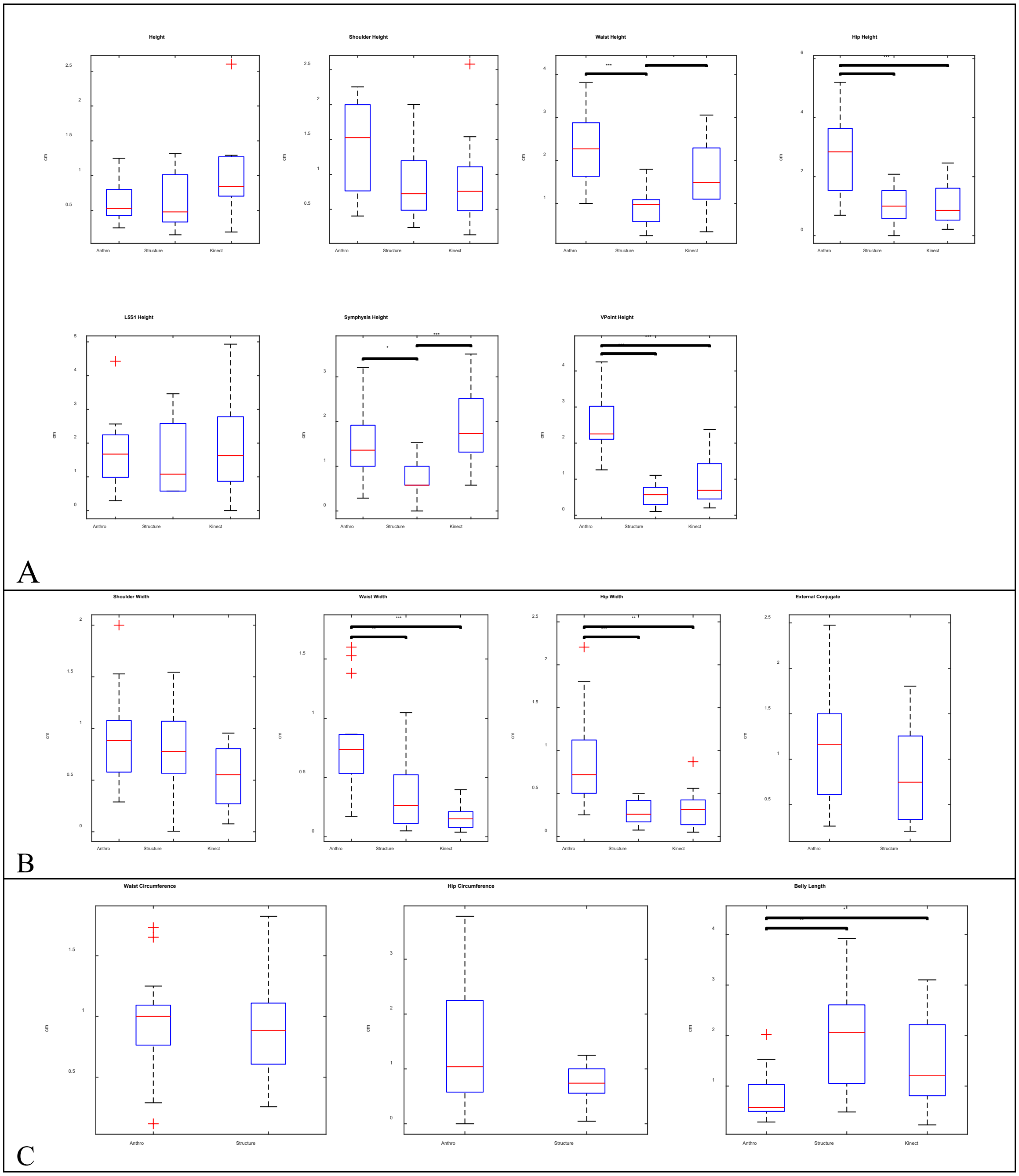

Figure 11– Variability Study – Variation Analysis with outlier removal
*Box plot of standard deviation (cm) for each comparative measurement from each modality, with heights in panel A, widths in B, and circumferences in C. Statistical significance was performed by Kruskal-Wallis one way analysis of variance in MATLAB. * indicates $p \leq .05$, ** indicates $p \leq .01$, and *** indicates $p \leq .001$. Points indicated by the red "+" are outliers 1.5 interquartile ranges above the 75th percentile or below the 25th percentile. Outliers indicated are newly calculated from the adjusted dataset.*

Table 2 – Variability Study – Variation Analysis with Outliers Removed

Analysis of standard deviations across measurements after the outliers from the raw data have been removed, indicating for each measurement, for all each modality, the median and interquartile range (25th quartile and 75th quartile) for the standard deviations for that measurement for all participants. Statistical significance was performed by Kruskal-Wallis one way analysis of variance in MATLAB. The P-values are stated for the comparison of Structure and Kinect measurements to the Anthropometric measurements, and for the comparison of the Structure and Kinect measurements to each other.

Variability Study Results - Variation Analysis of standard deviations for each subject - with Outlier Removal					
				p-value	
	Measurements	**Modality**	**Median (IQR) *cm***	**to Anthro**	**Kinect to Structure**
Heights	**Height**	Anthro	0.53 (0.43 - 0.80)		
		Structure	0.48 (0.34 - 1.02)	0.734	
		Kinect	0.85 (0.71 - 1.27)	0.374	0.092
	Shoulder Height	Anthro	1.53 (0.76 - 2.00)		
		Structure	0.72 (0.49 - 1.20)	0.037	
		Kinect	0.76 (0.48 - 1.11)	0.313	0.574
	Waist Height	Anthro	2.27 (1.63 - 2.88)		
		Structure	0.98 (0.58 - 1.09)	<.001	
		Kinect	1.49 (1.10 - 2.29)	0.190	0.033
	Hip Height	Anthro	2.84 (1.53 - 3.64)		
		Structure	1.00 (0.58 - 1.53)	0.001	
		Kinect	0.86 (0.53 - 1.61)	0.002	0.996
	L5S1 Height	Anthro	1.67 (0.98 - 2.24)		
		Structure	1.08 (0.58 - 2.58)	0.431	
		Kinect	1.63 (0.87 - 2.78)	0.955	0.610
	Symphysis Height	Anthro	1.36 (1.00 - 1.92)		
		Structure	0.58 (0.58 - 1.00)	0.051	
		Kinect	1.73 (1.32 - 2.52)	0.428	0.001
	VPoint Height	Anthro	2.25 (2.11 - 3.02)		
		Structure	0.57 (0.30 - 0.77)	<.001	
		Kinect	0.69 (0.45 - 1.43)	<.001	0.633
Widths	**Shoulder Width**	Anthro	0.88 (0.58 - 1.08)		
		Structure	0.78 (0.57 - 1.07)	0.794	
		Kinect	0.55 (0.27 - 0.80)	0.030	0.141
	Waist Width	Anthro	0.74 (0.53 - 0.86)		
		Structure	0.26 (0.11 - 0.52)	0.005	
		Kinect	0.15 (0.08 - 0.21)	<.001	0.374
	Hip Width	Anthro	0.72 (0.50 - 1.12)		
		Structure	0.26 (0.17 - 0.42)	<.001	
		Kinect	0.31 (0.14 - 0.43)	0.001	0.826
	External Conjugate	Anthro	1.16 (0.61 - 1.50)		
		Structure	0.75 (0.34 - 1.26)	0.221	
Circumferences	**Waist Circumference**	Anthro	1.00 (0.76 - 1.09)		
		Structure	0.88 (0.61 - 1.11)	0.718	
	Hip Circumference	Anthro	1.04 (0.58 - 2.25)		
		Structure	0.74 (0.56 - 1.00)	0.196	
	Belly Length	Anthro	0.58 (0.50 - 1.03)		
		Structure	2.06 (1.06 - 2.61)	0.006	
		Kinect	1.20 (0.81 - 2.22)	0.072	0.655

Average analysis

Analysis of the average measurement value for each subject indicates that some measurements are not obtained similarly in each modality (**Figure 12, Table 3**). Only the measurements of *waist height* and *symphysis height* had no differences between all three modalities, and *hip circumference* had no difference between the two modalities it was measured with, traditional anthropometry and Structure. The averages of measurements of *height* and *shoulder height* were lower for Kinect compared to Anthropometric measurements and Structure measurements, while the Structure measurements were similar to Anthro measurements. For the measurements *hip height, L5S1 height,* and *belly length*, both the Structure measurements and Kinect measurements were lower than the Anthropometric measurements, whereas for the measurement of *waist width* Structure was higher than both Anthro and Kinect, while Anthro and Kinect were similar. For the measurements *Vpoint Height, shoulder width, hip width, external conjugate,* and *waist circumference* each modality they were measured by was different from each other. These results indicate that there are differences in the definition of each measurement by each modality.

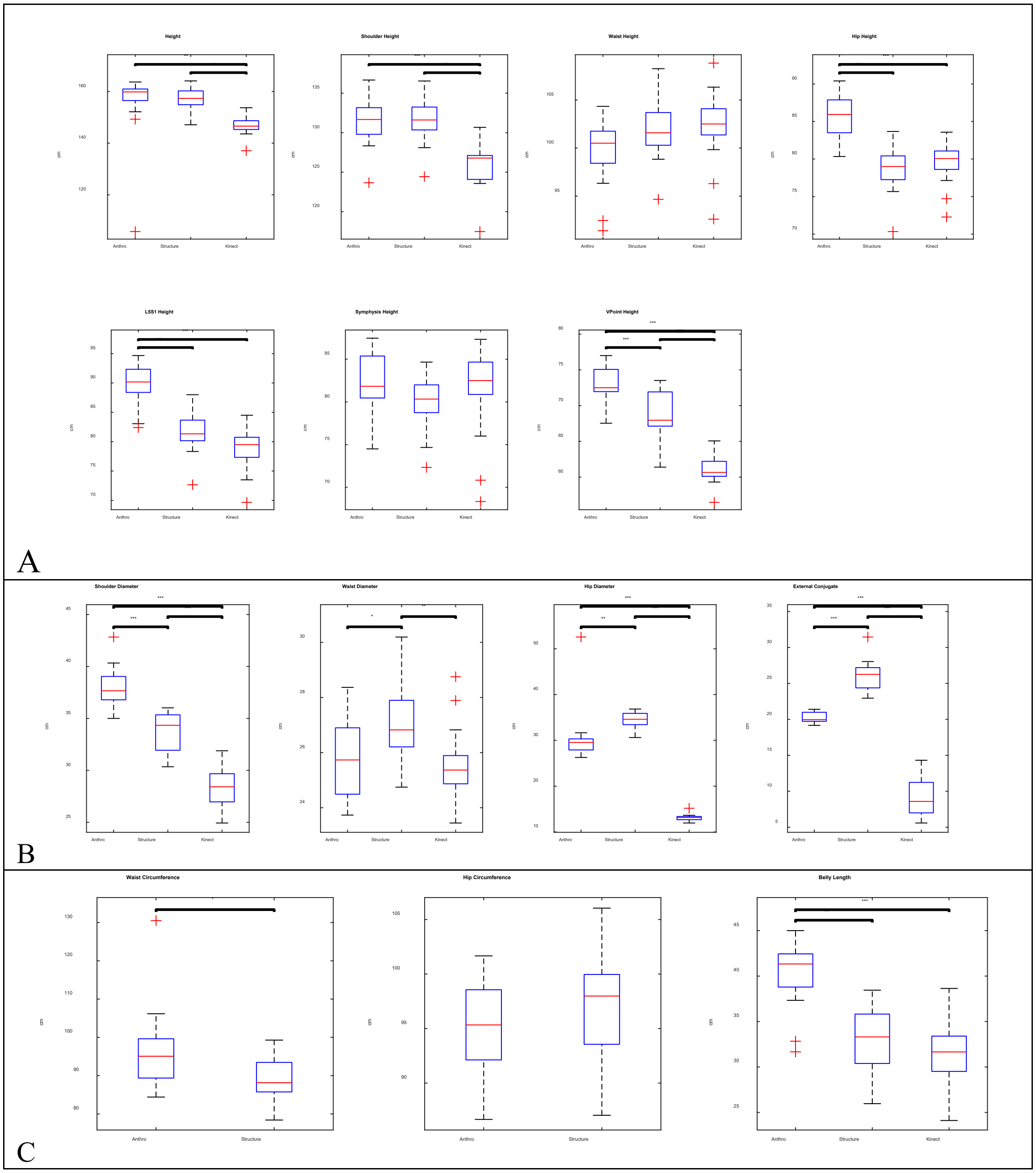

Figure 12 – Variability Study – Average Analysis
*Box plot of average measurements (cm) for each comparative measurement from each modality for all subjects (n=17), with heights in panel A, widths in B, and circumferences in C. Statistical significance was performed by Kruskal-Wallis one way analysis of variance in MATLAB. * indicates* $p \leq .05$, *** indicates* $p \leq .01$, and **** indicates* $p \leq .001$. *Points indicated by the red "+" are 1.5 interquartile ranges above the 75th percentile or below the 25th percentile.*

Table 3 – Variability Study – Average Analysis

Variability Study Results - Analysis of averages for each subject *(n=17)*						
					p-value	
	Measurements	Modality	Median (IQR) *cm*	Outliers	to Anthro	Kinect to Structure
Heights	Height	Anthro	159.83 (156.49 - 160.96)	3		
		Structure	157.33 (154.88 - 160.22)	0	0.734	
		Kinect	146.59 (145.29 - 148.67)	3	0.374	0.092
	Shoulder Height	Anthro	131.67 (129.79 - 133.17)	0		
		Structure	131.61 (130.35 - 133.24)	0	0.037	
		Kinect	126.78 (124.08 - 127.11)	3	0.313	0.574
	Waist Height	Anthro	100.50 (98.42 - 101.75)	2		
		Structure	101.58 (100.29 - 103.69)	1	<.001	
		Kinect	102.50 (101.36 - 104.09)	2	0.190	0.033
	Hip Height	Anthro	85.93 (83.50 - 87.88)	0		
		Structure	79.00 (77.25 - 80.42)	0	0.001	
		Kinect	80.06 (78.61 - 81.07)	1	0.002	0.996
	L5S1 Height	Anthro	90.17 (88.39 - 92.33)	1		
		Structure	81.33 (80.17 - 83.67)	0	0.431	
		Kinect	79.50 (77.33 - 80.75)	0	0.955	0.610
	Symphysis Height	Anthro	81.83 (80.46 - 85.38)	0		
		Structure	80.33 (78.75 - 82.00)	2	0.051	
		Kinect	82.50 (80.88 - 84.67)	2	0.428	0.001
	VPoint Height	Anthro	72.50 (71.96 - 75.07)	0		
		Structure	67.96 (67.13 - 71.92)	1	<.001	
		Kinect	60.65 (60.11 - 62.20)	0	<.001	0.633
Widths	Shoulder Width	Anthro	37.67 (36.79 - 39.04)	1		
		Structure	34.34 (31.93 - 35.35)	0	0.794	
		Kinect	28.42 (26.96 - 29.68)	0	0.030	0.141
	Waist Width	Anthro	25.73 (24.49 - 26.90)	1		
		Structure	26.82 (26.21 - 27.90)	0	0.005	
		Kinect	25.37 (24.87 - 25.89)	2	<.001	0.374
	Hip Width	Anthro	29.53 (27.91 - 30.32)	1		
		Structure	34.60 (33.44 - 35.89)	0	<.001	
		Kinect	13.14 (12.68 - 13.37)	2	0.001	0.826
	External Conjugate	Anthro	19.97 (19.73 - 20.98)	0		
		Structure	26.26 (24.38 - 27.19)	1	0.221	
Circumferences	Waist Circumference	Anthro	8.59 (7.00 - 11.23)	2		
		Structure	95.07 (89.37 - 99.63)	2	0.718	
	Hip Circumference	Anthro	88.15 (85.75 - 93.45)	0		
		Structure	95.33 (92.13 - 98.56)	2	0.196	
	Belly Length	Anthro	97.98 (93.56 - 99.96)	2		
		Structure	41.33 (38.79 - 42.44)	1	0.006	
		Kinect	33.31 (30.39 - 35.82)	1	0.072	0.655

Analysis of average of measurements across the three trials of the same modality, indicating for each measurement, for all each modality, the median, interquartile range (25^{th} quartile and 75^{th} quartile) and number of outliers. Statistical significance was performed by Kruskal-Wallis one way analysis of variance in MATLAB. The P-values are stated for the comparison of Structure and Kinect measurements to the Anthropometric measurements, and for the comparison of the Structure and Kinect measurements to each other.

Longitudinal Study - Variation of 3D Image & Traditional Anthropometry in measurements obtained over time

Variation analysis

For the longitudinal study analysis, 36 subjects were included, with 11 subjects having data from four visits, and 25 subjects having data from three visits. Analysis of the longitudinal data gives further evidence that the Structure measurements often has less variation than the Kinect measurements, and that the Structure measurements are comparable to the traditional anthropometric measurements (**Figure 13**,

Table 4). There was no difference in variation between the traditional anthropometric and Structure measurements for *shoulder height, waist height, shoulder width,* and *hip circumference,* but the measurement of *height* showed higher variation for Anthropometric compared to Structure, and the measurement of *hip height* showed higher variation for Structure compared to Anthropometric.

For the Kinect constant measurements, for the six measurements that had corresponding traditional anthropometric and Structure measurements, Kinect had higher variation than both traditional anthropometric and Structure for the measurements of *shoulder height* and *waist height,* had no different to neither traditional anthropometric nor Structure for *shoulder width,* was only worse than traditional anthropometric but similar to Structure for *height,* and was only worse than Structure but similar to traditional anthropometric for *hip height.*

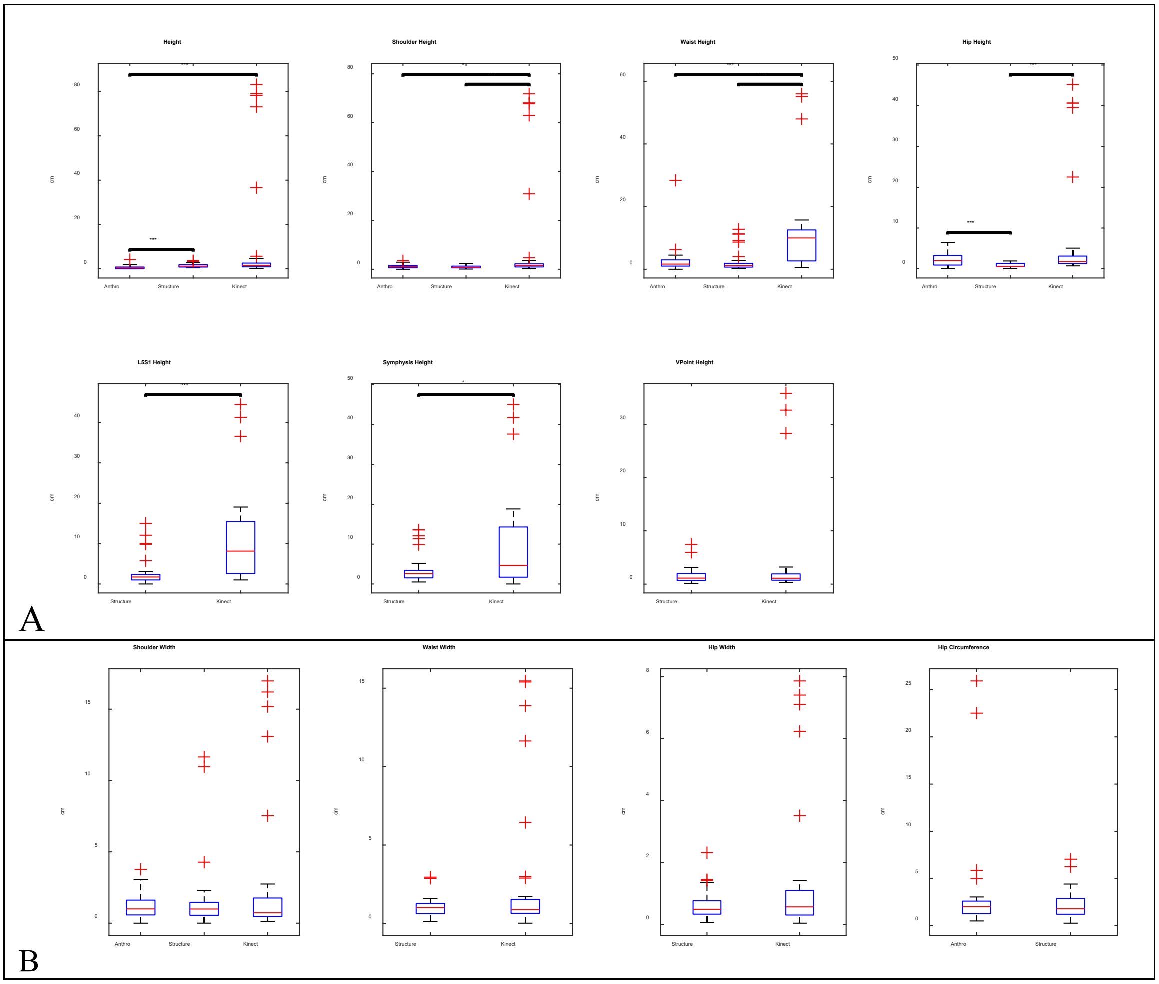

Figure 13 – Longitudinal Study – Variation Analysis
*Box plot of standard deviation (cm) for each comparative measurement for participants who attended 3 or 4 visits (n=36), with heights in panel A, widths in B, and circumferences in C. Statistical significance was performed by Kruskal-Wallis one way analysis of variance in MATLAB. * indicates* $p \leq .05$*, ** indicates* $p \leq .01$, and *** *indicates* $p \leq .001$. *Points indicated by the red "+" are 1.5 interquartile ranges above the 75*th *percentile or below the 25*th *percentile, although only those above the 75*th *quartile are considered outliers in Table 1..*

Table 4 - Longitudinal Study – Variation Analysis

Analysis of standard deviations across measurements, indicating for each measurement, for each modality, the median (cm), interquartile range (cm) (25th quartile and 75th quartile), and the number of outliers above the 75th quartile. Statistical significance was performed by Kruskal-Wallis one way analysis of variance in MATLAB. The P-values are stated for the comparison of Structure and Kinect measurements to the Anthropometric measurements, and for the comparison of the Structure and Kinect measurements to each other.

Longitudinal Study Results - Variation Analysis of standard deviations for each subject *(n=36)*						
					p-value	
	Measurements	**Modality**	**Median (IQR)** ***cm***	**Outliers**	***to Anthro***	***Kinect to Structure***
Heights	**Height**	Anthro	0.42 (0.00 - 0.81)	1		
		Structure	1.19 (0.79 - 1.80)	2	<.001	
		Kinect	1.54 (0.88 - 2.58)	6	<.001	0.669
	Shoulder Height	Anthro	1.00 (0.58 - 1.53)	1		
		Structure	0.79 (0.57 - 1.27)	0	0.869	
		Kinect	1.54 (0.93 - 2.20)	6	0.031	0.007
	Waist Height	Anthro	1.64 (1.00 - 2.99)	2		
		Structure	1.14 (0.68 - 1.90)	6	0.643	
		Kinect	9.98 (2.65 - 12.54)	3	<.001	<.001
	Hip Height	Anthro	1.99 (0.91 - 3.24)	0		
		Structure	0.58 (0.58 - 1.33)	0	<.001	
		Kinect	1.73 (1.25 - 3.12)	5	0.637	<.001
	L5S1 Height	Structure	1.73 (1.00 - 2.34)	5	n/a	
		Kinect	8.15 (2.58 - 15.45)	3	n/a	<.001
	Symphysis Height	Structure	2.57 (1.53 - 3.41)	5	n/a	
		Kinect	4.66 (1.71 - 14.30)	3	n/a	0.027
	VPoint Height	Structure	1.13 (0.70 - 1.98)	2	n/a	
		Kinect	1.11 (0.74 - 1.92)	3	n/a	0.901
Widths and Circumference	**Shoulder Width**	Anthro	1.00 (0.58 - 1.62)	1		
		Structure	0.99 (0.56 - 1.47)	3	0.998	
		Kinect	0.73 (0.47 - 1.76)	5	0.969	0.982
	Waist Width	Structure	1.01 (0.62 - 1.28)	2	n/a	
		Kinect	0.88 (0.65 - 1.53)	7	n/a	0.604
	Hip Width	Structure	0.50 (0.34 - 0.77)	3	n/a	
		Kinect	0.57 (0.31 - 1.10)	5	n/a	0.492
	Hip Circumference	Anthro	2.01 (1.27 - 2.60)	4		
		Structure	1.79 (1.21 - 2.87)	2	0.866	<.001

For the five constant measurements that only had Structure and Kinect measurements, Kinect had higher variation than Structure for the measurements of *L5S1height* and *symphysis height,* and had no difference for *VPoint height, waist width,* and *hip width.*

Nominal comparison of the number of outliers in each method shows that for measurements that had both traditional anthropometric and Structure measurements, there were a similar number of outliers between the modalities (Anthro = 9, Structure = 13), but for measurements that just had Structure and Kinect measurements, there were much more Kinect outliers than Structure (Structure = 28, Kinect = 46). These results suggest that the Kinect method might be more prone to outliers than the Structure and traditional anthropometric approaches.

Variation analysis with outlier removal

Similarly to the results from the Variability Study outlier adjustment results, adjustment through outlier removal for the Longitudinal Study dataset leads to mostly the same results (**Figure 14** and

Table 5**).** The only changes are for the Kinect measurements of *shoulder height* and *symphysis height,* as when outliers are removed from *shoulder height* Kinect no longer has higher variation than traditional anthropometric and Structure, and changes to being similar, and when outliers are removed from *symphysis height* Kinect changes from having higher variation to having similar variation in comparison to Structure.

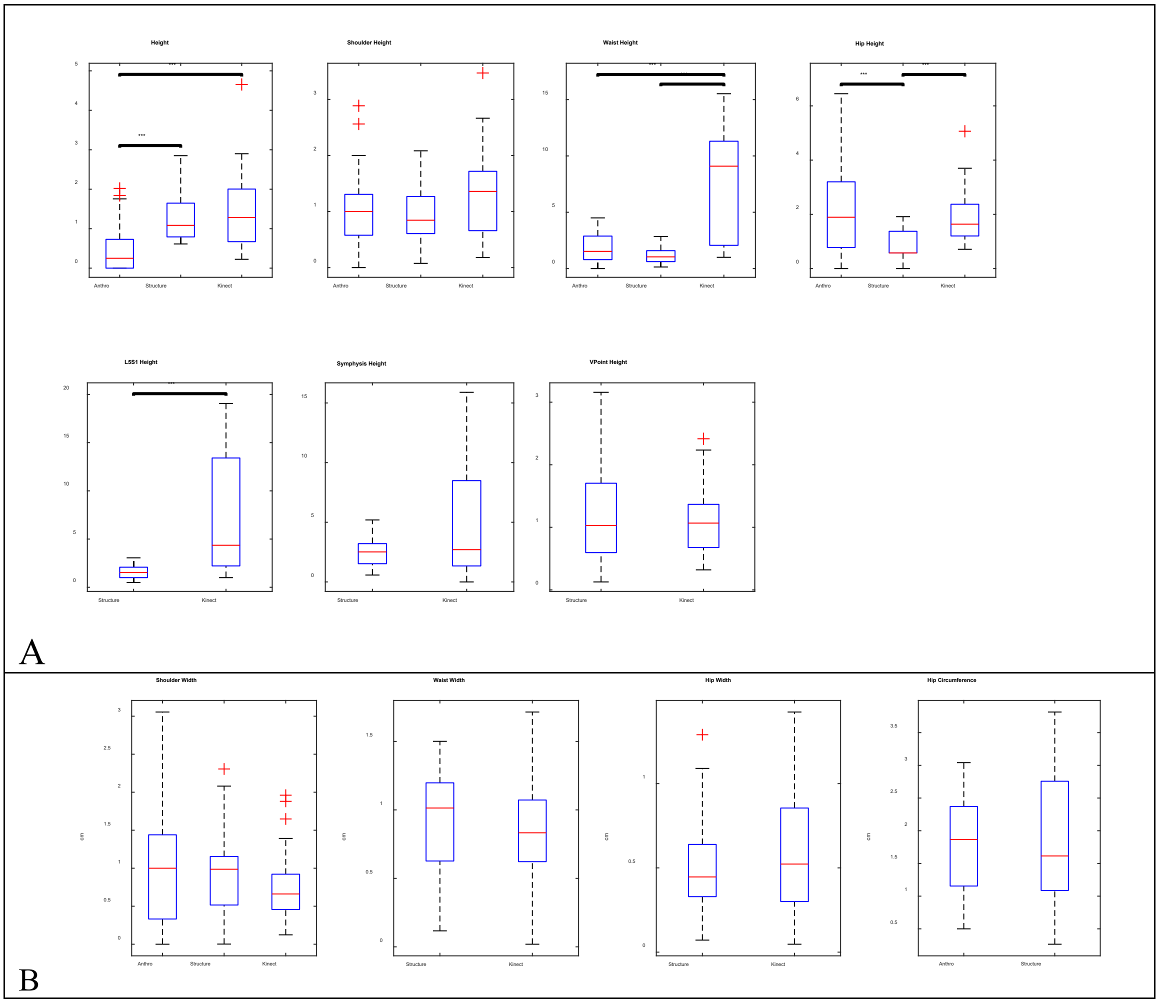

Figure 14 – Longitudinal Study – Variation Analysis with outlier removal
*Box plot of standard deviation for each comparative measurement for participants who attended 3 or 4 visits, with heights in panel A, widths in B, and circumferences in C. Statistical significance was performed by Kruskal-Wallis one way analysis of variance in MATLAB. * indicates* $p \leq .05$*, ** indicates* $p \leq .01$, and *** indicates* $p \leq .001$. *Points indicated by the red "+" are outliers 1.5 interquartile ranges above the 75th percentile or below the 25th percentile. Outliers indicated are newly calculated from the adjusted dataset.*

Table 5 - Longitudinal Study – Variation Analysis with Outliers Removed

Analysis of standard deviations (cm) across measurements for all subjects (n=36), indicating for each measurement, for all each modality, the median, IQR (25th and 75th percentile), and number of outliers. Statistical significance was performed by Kruskal-Wallis one way analysis of variance in MATLAB. The P-values are stated for the comparison of Structure and Kinect measurements to the Anthropometric measurements, and for the comparison of the Structure and Kinect measurements to each other.

Longitudinal Study Results - Variation Analysis of standard deviations for each subject - with outliers removed						
					p-value	
	Measurements	**Modality**	**Median (IQR) *cm***	**Outliers**	***to Anthro***	***Kinect to Structure***
Heights	**Height**	Anthro	0.25 (0.00 - 0.73)	1		
		Structure	1.08 (0.79 - 1.65)	2	<.001	
		Kinect	1.28 (0.67 - 2.00)	6	<.001	0.995
	Shoulder Height	Anthro	1.00 (0.58 - 1.31)	1		
		Structure	0.85 (0.61 - 1.27)	0	0.999	
		Kinect	1.36 (0.66 - 1.72)	6	0.142	0.129
	Waist Height	Anthro	1.53 (0.79 - 2.88)	2		
		Structure	1.04 (0.62 - 1.59)	6	0.301	
		Kinect	9.09 (2.07 - 11.31)	3	<.001	<.001
	Hip Height	Anthro	1.89 (0.78 - 3.20)	0		
		Structure	0.58 (0.58 - 1.38)	0	<.001	
		Kinect	1.64 (1.20 - 2.37)	5	0.924	<.001
	L5S1 Height	Structure	1.53 (1.00 - 2.08)	5	n/a	
		Kinect	4.36 (2.22 - 13.41)	3	n/a	<.001
	Symphysis Height	Structure	2.52 (1.53 - 3.21)	5	n/a	
		Kinect	2.70 (1.34 - 8.49)	3	n/a	0.228
	VPoint Height	Structure	1.03 (0.60 - 1.70)	2	n/a	
		Kinect	1.07 (0.68 - 1.37)	3	n/a	0.678
Widths and Circumfernce	**Shoulder Width**	Anthro	1.00 (0.33 - 1.44)	1		
		Structure	0.99 (0.52 - 1.15)	3	0.850	
		Kinect	0.66 (0.46 - 0.92)	5	0.427	0.763
	Waist Width	Structure	1.01 (0.63 - 1.20)	2	n/a	
		Kinect	0.83 (0.62 - 1.07)	7	n/a	0.388
	Hip Width	Structure	0.45 (0.33 - 0.64)	3	n/a	
		Kinect	0.52 (0.30 - 0.86)	5	n/a	0.781
	Hip Circumference	Anthro	1.87 (1.15 - 2.37)	4		
		Structure	1.61 (1.09 - 2.76)	2	0.882	<.001

Longitudinal analysis

Longitudinal analysis by visualization of the measurements obtained by each modality over time allows for analysis of both the different trends within modalities, and the differences between how some measurements are defined by each modality (**Appendix, Longitudinal Analysis**). Although this analysis is on the adjusted dataset with outliers removed, there still are clear issues with the Kinect modality, especially for the measurements of *waist height, L5S1 height, symphysis height,* and *belly length*. The measurements of *height*, *shoulder width,* and *hip width* are clearly defined differently with the different modalities.

CHAPTER 4 : DISCUSSION

Structure and Kinect cameras can be used to obtain anthropometric measurements from pregnant women in Ethiopia with similar variation to traditional anthropometry

Our findings show that when we used Structure and Kinect cameras to obtain 3D scans of pregnant mothers in Ethiopia, and processed these scans through the investigator's custom algorithm, the measurements obtained were often had similar variation to those obtained by a traditional anthropometric approach. When looking at the results from the four analysis (Variability Study with and without outliers, and the Longitudinal study with and without outliers) all together, it is evident that there are many measurements for which the Structure and Kinect measurements perform just as well as traditional anthropometry measurements, and there are more measurements in both Structure and Kinect that have lower variation compared to traditional anthropometry than those that have higher variation (**Figure 15**). It is important to note that not all measurements that were obtained by both modalities, for example the measurements of *Vpoint height, waist width,* and *hip width* were improved for both Structure and Kinect in comparison to traditional anthropometry in the variability study but had no comparisons in the longitudinal study since the corresponding traditional anthropometric measurement was not obtained. Further data with a larger sample size for all measurements could further illustrate the relationships of variation between these modalities. These findings are in line with the widespread usage of 3D scanning technology to obtain anthropometric measurements in a variety of applications, as described in the background section.

Structure to Anthro		Variability		Longitudinal	
		w. outliers	no outliers	w. outliers	no outliers
Heights	Height	o	o	-	-
	Shoulder Height	+	o	o	o
	Waist height	+	+	o	o
	Hip Height	+	+	+	+
	L5S1 Height	o	o	n/a	n/a
	Symphysis Height	o	+	n/a	n/a
	Vpoint Height	+	+	n/a	n/a
Widths	Shoulder Width	o	o	o	o
	Waist Width	+	+	n/a	n/a
	Hip Width	+	+	n/a	n/a
	External Conjugate	o	o	o	o
Circumferences	Waist Circumference	o	o	n/a	n/a
	Hip Circumference	o	o	o	o
	Belly Length	-	-	n/a	n/a
Totals	**Improved**	**6**	**6**	**1**	**1**
	Same	**7**	**7**	**5**	**5**
	Worse	**1**	**1**	**1**	**1**
Kinect to Anthro					
		Var	Var Adjusted	Long	Long adjsuted
Heights	Height	o	o	-	-
	Shoulder Height	o	o	-	o
	Waist height	o	o	-	-
	Hip Height	+	+	o	o
	L5S1 Height	o	o	n/a	n/a
	Symphysis Height	o	o	n/a	n/a
	Vpoint Height	+	+	n/a	n/a
Widths	Shoulder Width	+	o	o	o
	Waist Width	+	+	n/a	n/a
	Hip Width	+	+	n/a	n/a
	External Conjugate	n/a	n/a	o	o
Circumferences	Waist Circumference	n/a	n/a	n/a	n/a
	Hip Circumference	n/a	n/a	o	o
	Belly Length	o	-	n/a	n/a
Totals	**Improved**	**5**	**4**	**0**	**0**
	Same	**6**	**6**	**4**	**5**
	Worse	**0**	**1**	**3**	**2**
Kinect to Structure					
		Var	Var Adjusted	Long	Long adjsuted
Heights	Height	o	o	o	o
	Shoulder Height	o	o	-	o
	Waist height	-	-	-	-
	Hip Height	o	o	-	-
	L5S1 Height	o	o	-	-
	Symphysis Height	-	-	-	o
	Vpoint Height	o	o	o	o
Widths	Shoulder Width	o	o	o	o
	Waist Width	o	o	o	o
	Hip Width	o	o	o	o
	External Conjugate	n/a	n/a	o	o
Circumferences	Waist Circumference	n/a	n/a	n/a	n/a
	Hip Circumference	n/a	n/a	o	o
	Belly Length	o	o	n/a	n/a
Totals	**Improved**	**0**	**0**	**0**	**0**
	Same	**9**	**9**	**7**	**9**
	Worse	**2**	**2**	**5**	**3**

Figure 15 – Comparison of results from Variabiliy Study both with and without outliers, and Longitudinal Study both with and without outliers, for the three categories of comapring Structure to Anthro, Kinect to Anthro, and Kinect to Structure. Improved measurements are those with lower variation, and are indicated in green and with a "+". Similar measuremetns are those with similar variation, and are indicated in blue and with a "o". Worse measurmetns are those with highier variation, and are indicated in red and with a "-". The total number of improved measurements, similar measuremetns, and worse measuremetns is totaled for each comparison category.

Structure may perform better than the Kinect

In this work, results of the Structure method generally performed better than the Kinect method, with the Structure measurements often having less variation or similar variation than the traditional anthropometric approach, and the Kinect measurements often having higher variation or similar variation as the traditional anthropometric measurements (**Figure 15**). Specifically, when directly comparing the Kinect measurements to Structure measurements across all four analyses conducted in this work, there were no measurements where Kinect had lower variation in comparison to traditional anthropometry, 9 with similar variation, and 3.5 with higher variation. Other studies have also found that while the Kinect platform can be used for obtaining anthropometric measurements, it often does not show lower variation in comparison to traditional anthropometry. For instance, a study on 37 participants (17 female and 20 male) that used both traditional anthropometry and a Kinect cameras and algorithm platform to obtain similar anthropometric measurements to those obtained in this study, the researchers found that generally, a manual approach was better for most measurements, although the Kinect method was within an acceptable range of deviation for their intended application of scanning for garment development (Bragança et al., 2018).

Limitations of traditional anthropometry

One limitation of the traditional anthropometric measurement data in this work is that its standard deviations may be artificially low due to the easy access data collectors had to previous measurements. When data collectors collected a repeated set of measurements, they had easily available to them the measurements obtained in a previous trial or visit, as all of the traditional anthropometric measurements were handwritten in one physical packet per subject. Although data collectors were trained both in the Variability study and the Longitudinal study to not look at these previous results when taking new results, it is possible that they did view these results, and were biased by them or even copied them, thereby making the traditional anthropometric measurement standard deviations mistakenly lower than they would have been taken entirely independently. Although duplicate measurements cannot be solely attributed to this bias, one data collector did inform the investigators that she had started copying repeated measurements on the Longitudinal study in order to save time. Although the investigators believe this nurse started this approach after the data from this study was already collected, it is possible she or others were doing it for this data as well. This issue could be addressed in future studies by improving the blinding process.

In general, as discussed previously in the introduction, traditional anthropometry is known to have issues with accuracy and variation, and variability can occur in how data collectors define the measurements on the variously shaped bodies of participants. Additionally, the process of obtaining many traditional anthropometric measurements can be very cumbersome for the participant. In fact, several participants in the Variability Study opted to stop data collection partway through the needed three repetitions of traditional anthropometric data collection, indicating that the process was taking too long, and they were uncomfortable standing for so long. This phenomenon indicates that in addition to suffering from subjectivity, the traditional anthropometric approach may not be liked by participants.

Limitations and benefits of 3D camera-based anthropometry

There are several limitations within both the Structure and Kinect 3D scanning methods that could have influenced their variation in these studies. Firstly, the data collectors who obtain the 3D scans have many opportunities to introduce variability into the data collection. Although each data collector was well trained and were occasionally observed by the investigator to ensure the procedure was still being followed properly, it is possible that variation in their instructions to the participants or within their scanning technique could influence the results. If the participant moves during scanning, if their arms and legs are not positioned correctly, or the participant is too far from the scanner, the scan quality can suffer. For Structure, scan quality can also suffer if the nurse moves around the patient too quickly when obtaining the scan, and for Kinect, variability could be introduced if the Kinect camera is not placed at the same location each day. If the scan is not an accurate representation of the participant's body, the subsequent measurements from that scan cannot have low variation. For this reason, nurses were trained to redo scans if they determined that the scan quality was poor. However, they may have elected to not redo the scan when they should have, or they may incorrectly classify a scan as acceptable when it really would not. Potential improvement could be made by imbedding more stringent verifications of scan quality within the methods, such as by the software automatically detecting if a scan is bad and forcing the nurse to redo the scan (this feature exists in the Kinect method but not the Structure), or by fixing the Kinect camera to a surface so that it cannot be moved. Additionally, during training and at checkpoints within data collection, nurses could be asked to obtain scans on a mannequin with known dimensions, to ensure that their technique is still up to standard.

Secondly, environmental factors within the room could potentially introduce variability to the scans, thereby impacting the measurements. The rooms within the health centers where the study was conducted often had abundant natural light which fluctuate depending on the weather and time of day. Although both the Structure and Kinect cameras are marketed as being able to be used in a wide variety of lighting conditions, it is possible that the scans obtained at different times of days have a difference in quality that could impact the result. Future studies could be done by obtaining scans of a static object or participant at various times of day and comparing the variation of these scans in comparison to scans obtained within the same lighting.

Thirdly, it is possible that variation could be introduced by the physical hardware of the scanning devices used. Physical warping of the device could occur from heat exposure or being dropped, which could impact scan quality and therefore measurements. As various cameras were used throughout the study, it is possible that some cameras introduced their own variability to the data. Although analysis of this dataset found no significant differences in the scans obtained from one particular camera, it is possible that small differences existed that were not detected. More consistent calibration could potentially address this potential issue. For this study, each Structure camera was calibrated through the Occipital calibration software once at the start of that camera's use in a new location, or as requested by the Occipital structure. The Kinect cameras were not recalibrated. In future studies, investigators could be sure to both recalibrate the software of the cameras after a certain amount of time or number of uses and could also calibrate the camera by regularly scanning an object of a known size and ensuring the scan is scaled correctly. These steps could ideally identify potential physical hardware issues with the cameras.

Despite these limitations, there are still several advantages to the 3D scanning platform. Obtaining a 3D scan takes much less time than obtaining traditional anthropometric measurements, especially when considering that from a 3D scan, an extremely large number of different anthropometric measurements could be simultaneously obtained. This decrease in acquisition time should increase comfort for the pregnant mothers being measured. Additionally, some traditional anthropometric measurements require specialized equipment beyond a tape measure, such as a length board to measure height, and an anthropometric caliper to measure widths. These tools can be difficult to transport to Ethiopia or obtain in Ethiopia. In addition to these shared benefits, there are several advantages of the Structure platform in comparison to the Kinect platform. The Structure method has the additional benefits of being cheaper and requiring less maintenance, as it does not depend upon a laptop computer to run the scanning acquisition software, or continuous power for charging. For these reasons of lower variation in these results, and the other benefits this platform provides, we recommend using the Structure camera, rather than the Kinect camera, for future development of a 3D camera based CPD risk assessment tool.

Physical characteristics of measurements may impact variation potential

Although many anthropometric measurements are able to be identified from 3D scans, some measurements have much less variation than others, as shown by our results. Similarly, there is a wide variety of levels of variation among the traditional anthropometric measurements. Some measurements may be more easily obtained by a specific modality due to physical characteristics of the landmarks used to obtain that measurement. For example, the traditional anthropometric measurement of *belly length* in the Variability Study was measured manually by palpating for the bottom of the sternum and measuring from this point to the bottom of the belly protrusion of the participant. As the Structure and Kinect measurements can only come from the surface of the body, they may be unable to replicate the low variation that comes with being able to palpate for bony features. Therefore, it follows that the *belly length* measurement's reliance on palpation may have led it to have less variation in the traditional anthropometric measurement in comparison to when it is obtained by 3D scans. However, for measurements that do not rely on bony features, the traditional anthropometric measure may be more subjective than the 3D scanning method. For example, the measurements of *waist width* and *hip width* in the Variability Study may have less variation in the 3D scanning methods than traditional anthropometry because they are dependent on identifying the widest and narrowest part of the torso, which may be subjective when not done by a computer. Additionally, the anthropometric calipers used to obtain these measurements create a large potential for variability, as the nurse could push the calipers slightly into the skin by a different amount each time they measure. For the measurement of *height*, the hairstyle of the participant may introduce variability in the 3D scan modalities, because the measurement will be obtained from the top of the hair. This variation may not be present in the traditional anthropometric *height* because the nurse can push the top of the length board down onto the participant's head and flatten the hair.

The phenomena of some measurements having physical characteristics that make them perform better in different modes is also found in other studies. For instance, in

Bragança *et al.*, the measurement of *shoulder width* (which is comparable to the investigator's measurement of *shoulder width*) was found with much less variation in the manual approach than the Kinect 3D approach, but their measurements of *waist circumference* and *hip circumference* had similar or slightly worse variation than that obtained by the 3D measurements. Bragança *et al.*, suggest that this is because manual measurement often involves the palpation of skeletal landmarks to obtain the given measurement, and this palpation process is not possible with 3D scans. Although the Kinect *shoulder width* measurement in this work did not suffer the same worse variation as Bragança *et al.*'s *shoulder width*, the principle does persist that some measurements have physical characteristics that make them more challenging to measure with certain methods. Future studies can use this finding to ensure that the measurements obtained by as specific modality are properly best suited for being obtained by that modality, such as by only using measurements that rely on boney, less subjective landmarks in traditional anthropometry, and by using measurements that do not require palpation in 3D camera-based anthropometry.

Exploring accuracy despite differences of measurement definitions

Another important finding is that the measurements can sometimes significantly differ in average values between modalities. This difference could occur because of attributes of the 3D scans, or because of how the measurement is defined. For example, one important and distinct attribute of the Kinect scans in comparison to the Structure scans is that the Kinect scanning software identifies the bottom of the participant's feet and differentiates them from the floor of the room, while the Structure scans includes the entire floor within its scan. This difference in floor recognition might have led to a difference in the *height* measurements because the Structure scan's inclusion of the floor allows the algorithm to align the scan more accurately on the y=0 axis. The Kinect scan sometimes did not fully scan the feet, instead cutting the scan off at the ankles, which could potentially cause errors when attempting to align the scan with the y=0 axis. This may be why for the *height* measurements, oftentimes the Structure values were closer to the traditional anthropometric values than the Kinect values, while the Kinect measurements are less similar. In this way, if the traditional anthropometric measurement is assumed to be the "true value" for these measurements, this analysis could be understood as an evaluation of accuracy, with Structure being more "true" than the Kinect value.

However, this approach should not be used to understand all differences, because for some measurements, the reason for the differences may be because the algorithm simply identifies different points on the body than the anthropometric measurements. As described previously, as traditional anthropometry can use physical palpation, while 3D camera-based anthropometry cannot, it follows that some measurements would have to be defined differently between the approaches. These differences are made clear in the "Measurement Descriptions" section of the methods. For example, for the measurement of *hip width,* the manual measurement was obtained palpation of the hip bone, but in the Structure algorithm, this point was instead identified on each side as the widest part of the hip. This difference does not indicate an issue with either approach, but rather that they simply based on a slightly different anatomical landmark. Therefore, this analysis of averages should not always be understood to be an evaluation of accuracy, as the differences of the specific anatomical landmarks use to make measurements by each modality are not the same across modalities. It is for this reason that this work focused instead on comparing the variation of the measurements obtained by each modality.

Comparison to static mannequin anthropometric measurements

In this study, all scans were taken from human participants who, for the Variability Study may have slightly shifted position in between scanning trials, or for the Longitudinal Study were being scanned at entirely different time points during pregnancy. Considering this potential confounding factor, a potential way to evaluate variation could be to obtain measurements from a static mannequin. Additionally, this approach could be used to explore accuracy, as the mannequin could be manufactured with pre-determined “true” measurements. Although this process was not deeply explored in this study, the results are still similar to those obtained by a team who did undertake the process of comparing Structure 3D camera-based measurements to traditional anthropometric measurements of a mannequin, again for the application of garment making (Xia et al., 2019). Their 3D scans were processed through a similar algorithm to that used in this study which obtained various anthropometric measurements. Although these measurements are obtained from a static mannequin, when comparing the boxplots of results from 30 iterations of obtaining measurements on a mannequin, it is evident that the tape measurements often varied in average from the Structure measurements, even when having a similar interquartile range, and for some measurements both the tape measurements and Structure measurements sometimes varied from the “true values” defined by the mannequin manufacturer. This comparison illustrates that it is expected that traditional anthropometric and 3D-camera based measurements would vary in their averages, and that even tape measurements should not necessarily be used as the "true values." Future work for the Gleason Lab could involve a similar study that evaluated the repeatability of the measurements obtained on a static mannequin, although it would be important to ensure that the mannequin is representative of pregnant women in Ethiopia.

Implications for CPD risk score development

As discussed in the introduction, understanding the variation of different measurements from different modalities is important for development of a robust risk score for CPD. It very important that women are given a correct assessment of their CPD risk, and large variation within the measurements used to determine that risk could lead to an incorrect assessment of their risk. The analysis of variation in this study is important for two main reasons. Firstly, it is valuable to understand if specific modalities have overall trends in having lower or higher variation compared to other modalities, so that choices can be made of which modality to focus on in future work. Specifically, this work showed that overall, the Structure modality often has less variation in its measurements than Kinect, which points towards utilizing the Structure tool exclusively going forward. This selection will streamline future work, allowing the team to focus on making a high-quality tool with the Structure platform. Secondly, this work is valuable because it demonstrates which measurements are more likely to have lower variation and which measurements are more likely to have higher variation within a modality. This information could be used to inform the selection of measurements to be used in the CPD risk score, for example by only including measurements in the model that are shown to have a low variation. This step of only including high quality measurements was not thoroughly done in previous versions of the CPD risk score, as variation information about the measurements was not obtained in these former studies. Therefore, in these previous scores, a measurement may have been a key feature for determining risk out of the data from that study, but if that measurement had high variation, its correlation with CPD risk could be a result of overfitting and would not hold up to new data. The CPD risk score that will be used in future versions of this work has not been created yet, as this work had to be done first to demonstrate which modality and measurements are best to include in this model. Future work should include analysis of how variation impacts the risk assessment, for example quantifying how sensitive the model is to variations within a measurement. With this threshold better understood, the measurement tools could be further developed to ensure they perform within the acceptable amount of variation that still produces correct calculations of CPD risk.

Conclusion

This work demonstrated the feasibility of using Structure and Kinect 3D cameras to obtain measurements of pregnant women in Ethiopia, which ultimately can be used to form risk scores to predict the life-threatening condition of CPD. Evaluation of variation showed that the Structure camera method especially performed as well or even better than traditional anthropometry, which gives further support to the continued use and development of this novel tool. The limitations of the traditional anthropometric approach highlight the potential of 3D-camera based anthropometry as an exciting alternative, especially in the dramatically reduced time needed to obtain a multitude of measurements. The potential confounding factors of data collectors, environmental factors, and hardware malfunctions should be further analyzed and designed for in future studies. In development of a tool to predict CPD using 3D camera based anthropometric measurements, attention should be given towards choosing measurements that are specifically suited to this modality due to their physical characteristics and specific definitions. A mannequin that replicates the shape of the body of a pregnant woman in Ethiopia could be used in an additional variability study to further understand the variation of the 3D camera-based measurements. In conclusion, this work supports the continuation of the Gleason Lab's work towards developing a 3D camera-based tool for prediction of CPD in Ethiopia.

APPENDIX

Variability Study Questionnaire

Y7በምርምር ጥናቱ ውስጥ አዋቂ ተሳታፊዎችን ለማሳተፍ የተዘጋጀ የፈቃድ ሰነድ

አዲስ አበባ ዩኒቨርስቲ፣ የጤና ሳይንስ ኮሌጅ

የስምምነት ማጠቃለያ፡

“በኢትዮጵያ ውስጥ በብሔራዊ ደረጃ በእርግዝና ወቅት የእናት ዳሌ ከሽል ጭንቅላት አንሶ የሚገኝበትን አደጋ ለመወሰን ዝቅተኛ ወጪ ያለውን፣ የዳበሰ እና የመነካካት ቴክኖሎጂን መጠቀም” በተሰኘው የምርምር ፕሮጀክት ተሳትፎ እንዳደርግ ተጠየቅሁ። በተያያዘው በመረጃ የተደገፈ የስምምነት ሰነድ ውስጥ በተጠቀሰው መሠረት በዚህ ጥናት ውስጥ የመካተት ሥነምግባርን ግንዛቤዎችን እና ጥቅሞቹን ተረድቻለሁ እናም ይህ ምርመራ የእንቅስቃሴ ለይ እና አወቃቀር ሴንሰር (አነፍናፊ) መለኪያዎች እና የቴፕ ልኬት መለኪያዎችን እንደሚያካትት ተረድቻለሁ። እንዲሁም ከእኔ የተሰበሰበው መረጃ ሁሉ በሚስጢር እንደሚያዝ ተነግሮኛል።

ምክንያቶቹን ለማንም ማስረዳት ሳያስፈልግ በማንኛውም ጊዜ መረጃን የመከልከል፣ ትብብርን የመከልከል ወይም ከጥናቱ የማቋረጥ መብት እንዳለኝ፣ እና እርምጃዎቼ በእርግዝናዬ አጠቃላይ የምርመራ ሂደት ላይ ምንም ዓይነት ተጽዕኖ እንደማይኖራቸው አውቃለሁ። ደግሞም በማንኛውም ጊዜ ማብራሪያ የመጠየቅ እና የማግኘት መብት እንዳለኝ አውቃለሁ። ጥርጣሬ ወይም ጥያቄ ቢኖርብኝ ዶክተር ማህሌት ይገረሙን በ+251-911603184 ማግኘት እችላለሁ ወይም አዲስ አበባ ዩኒቨርሲቲ አይአርቢ ጽ/ቤት (አዲስ አበባ ዩኒቨርሲቲ፣ የጤና ሳይንስ ኮሌጅ፣ ጥቁር አንበሳ ስፔሻላይዝድ ሆስፒታል አዲስ ህንፃ፣ 8ኛ ፎቅ) በ25-111-15513099) ማግኘት እችላለሁ።

ማብራሪያ ጠይቄ በምረዳው ቋንቋ አጥጋቢ ምላሾች አግኝቻለሁ። መልስ ለመስጠት በቂ ጊዜ ተሰጥቶኛል። ፊርማዬን በማስቀመጥ በመጨረሻ ስምምነቴን አረጋግጣለሁ።

____

የተሳታፊ ስም (ታትሟል)

______________________________ __________ __________

የተሳታፊ ፊርማ ቀን ሰዓት

______________________________ ____________________

ስምምነትን የሚያገኝ ሰው ፊርማ ቀን

Recruiting Nurse, fill out information below:

Participant Number: V3 - ____ ____ ____

(Participant ID)

Hospital Card Number: ____ ____ ____ ____ ____ ____ Date: __ __ / __ __ / __ __ __ __ (E.C.)

Participant Phone Number: ____

Questionnaire for Inter-User Variability Study

Q No.	Questions and Filters	Codes	Response
101	Region ID	Addis Ababa…..01 Adama……………02 Hawassa…………03 Jimma………..04 Mekelle……..05 Gondar………06	_____ _____
102	Site ID initials	Tikur Anbessa..01 Girar………………02 Woreda 08….03 Other…………99	_____ _____
103	Participant Identification Number	V3###	V 3 ____ ____ ____
104	Participants Initials	XXX	____ ____ ____
105	Hospital Card Number	######	___ ___ ___ ___ ___ ___
106	Nurse Initials	XXX	____ ____ ____
107	Date of recruitment & filling out this form. USE ETHIOPIAN CALENDAR	Date ___ ___ / ___ ___ / ___ ___ ___ ____ (day) (month) (year)	
108	How old was the participant on their last birthday? PROBE USING HISTORICAL EVENTS TO APPROXIMATE AGE, IF UNKNOWN	Age (in years)............... ## If not 18-40 years old >> STOP! Exclusion Criteria	_____ _____
109	What is the gestational age of the participant? If below 28 >> STOP! Exclusion Criteria	Weeks + days......... ## + #	____ ____ + ____
110	How was the gestational age determined?	Recalled days from last menstruation......... 1 Ultrasound................... 2 Other............................ 3	____
111	Is this a singleton pregnancy?	Yes.......... 1 No........... 2 >> STOP! Exclusion Criteria	____
112	Is this your first pregnancy?	YES........... 1 No........... 2 >> STOP! Exclusion Criteria	____
113	What region is your mother from?	Tigray......................... 01 Afar........................... 02 Amhara..................... 03 Oromia...................... 04 Somalie..................... 05 Benshagul Gumuz..... 06 SNNP..................... 07 Gambella................ 08 Harari..................... 09 Addis Ababa........... 10 Diredawa............... 11 Outside Ethiopia.... 12 Don't know..............98	____
114	What region is your father from?		____
115	Where did you live until the age of 15?		____
116	What region do you currently live in?		____
117	Does this participant plan for trial of labor?	Yes................................ 1 No................................. 2	____
118	Where does the participant plan to deliver?	Tikur Anbessa .... 1 Other.............. 2 - Specify: _____________	_____

119	What is the fetal presentation?	Vertex……………………………1 Other…………………………..2	

Anthro Measurements – Nurse 1			
101	Questions and Filters	Codes	Response
102	Identifier	Participant ID	V 3 ____ ____ ____
103	Nurse ID	GB……………………01 FK……………………02 WS……………………03 TT……………………04	____ ____
104	Trial Number	#	1
105	Height	Height (in cm)………………. ###.#	_____ _____ _____ . _____
106	Head Circumference	Circumference (in cm)…… ##.#	_____ _____ . _____
107	Shoulder Width	Width (in cm)………………. ##.#	_____ _____ . _____
108	Shoulder Height	Height (in cm)……………. ###.#	_____ _____ _____ . _____
109	Waist Height	Height (in cm)………………###.#	_____ _____ _____ . _____
110	Intertrochanteric Height	Height (in cm)………………. ###.#	_____ _____ _____ . _____
111	L5S1 Height	Height (in cm)…………..………##.#	_____ _____ . _____
112	Symphysis Height	Height (in cm)…………..………##.#	_____ _____ . _____
113	V-Point Height	Height (in cm)…………..………##.#	_____ _____ . _____
114	Waist Circumference	Circumference (in cm)…… ###.#	_____ _____ _____ . _____
115	Intertrochanteric (hip) Circumference	Circumference (in cm)…… ###.#	_____ _____ _____ . _____
116	Belly Length	Height (in cm)………………##.#	____ ____ . ____
117	Waist Width	Width (in cm)……………. ##.#	_____ _____ . _____
118	Intertrochanteric Width	Width (in cm)……………. ##.#	_____ _____ . _____
119	External Conjugate	Width (in cm)……………. ##.#	_____ _____ . _____

Structure Measurements – rounds 1-3	
66	COLLECT 3 STRUCTURE SCANS. Email the scans after the subject has left the study room, to save time. ☐ Scan 1 - File name: V1 – Patient Number – Camera Number (For example = V1 – 001 – 1) ☐ Scan 2 - File name: V1 – Patient Number – Camera Number (For example = V1 – 001 – 2) ☐ Scan 3 - File name: V1 –Patient Number – Camera Number (For example = V1 – 001 – 3)

Anthro Measurements – Nurse 2			
101	Questions and Filters	Codes	Response
102	Identifier	Participant ID	V 3 ____ ____ ____
103	Nurse ID	GB……………………01 FK……………………02 WS……………………03 TT……………………04	____ ____
104	Trial Number	#	2
106	Height	Height (in cm)………………. ###.#	_____ _____ _____ . _____
108	Head Circumference	Circumference (in cm)…… ##.#	_____ _____ . _____
109	Shoulder Width	Width (in cm)………………. ##.#	_____ _____ . _____
110	Shoulder Height	Height (in cm)……………. ###.#	_____ _____ _____ . _____
111	Waist Height	Height (in cm)………………..###.#	_____ _____ _____ . _____
112	Intertrochanteric Height	Height (in cm)………………. ###.#	_____ _____ _____ . _____
114	L5S1 Height	Height (in cm)……….……….##.#	_____ _____ . _____
114	Symphysis Height	Height (in cm)……….……….##.#	_____ _____ . _____
115	V-Point Height	Height (in cm)……….……….##.#	_____ _____ . _____
116	Waist Circumference	Circumference (in cm)…… ###.#	_____ _____ _____ . _____

117	Intertrochanteric (hip) Circumference	Circumference (in cm)...... ###.#	_____ _____ _____ . _____
118	Belly Length	Height (in cm)…………………##.#	____ ____ . ____
119	Waist Width	Width (in cm)................ ##.#	_____ _____ . _____
120	Intertrochanteric Width	Width (in cm)................ ##.#	_____ _____ . _____
122	External Conjugate	Width (in cm)................ ##.#	_____ _____ . _____
Kinect Measurements – Nursess 1-3			
166	COLLECT 3 KINECT SCANS. Check confirming the collection and saving of the Kinects Scan on the external hard drive. ☐ Scan 1 - File name: V1 – Patient Number – Camera Number (For example = V1 – 001 – 1) ☐ Scan 2 - File name: V1 – Patient Number – Camera Number (For example = V1 – 001 – 2) ☐ Scan 3 - File name: V1 –Patient Number – Camera Number (For example = V1 – 001 – 3)		
Anthro Measurements – Nurse 3			
101	Questions and Filters	Codes	Response
102	Identifier	Participant ID	V 3 ____ ____ ____
103	Nurse ID	GB……………………01 FK…………………….02 WS……………………03 TT……………………..04	____ ____
104	Trial Number	#	**3**
105	Blood Pressure	Systolic / Diastolic (in mmHg)……………………….###/###	___ ____ ____ /____ ___ ___ SYSTOLIC / DIASTOLIC
106	Height	Height (in cm)………………. ###.#	_____ _____ _____ . _____
108	Head Circumference	Circumference (in cm)…… ##.#	_____ _____ . _____
109	Shoulder Width	Width (in cm)………………… ##.#	_____ _____ . _____
110	Shoulder Height	Height (in cm)……………. ###.#	_____ _____ _____ . _____
111	Waist Height	Height (in cm)………………..###.#	_____ _____ _____ . _____
112	Intertrochanteric Height	Height (in cm)………………. ###.#	_____ _____ _____ . _____
114	L5S1 Height	Height (in cm)………..………##.#	_____ _____ . _____

114	Symphysis Height	Height (in cm)……….………##.#	_____ _____ . _____
115	V-Point Height	Height (in cm)……….………##.#	_____ _____ . _____
116	Waist Circumference	Circumference (in cm)…… ###.#	_____ _____ _____ . _____
117	Intertrochanteric (hip) Circumference	Circumference (in cm)…… ###.#	_____ _____ _____ . _____
118	Belly Length	Height (in cm)………………..##.#	____ ____ . ____
119	Waist Width	Width (in cm)……………. ##.#	_____ _____ . _____
120	Intertrochanteric Width	Width (in cm)……………. ##.#	_____ _____ . _____
122	External Conjugate	Width (in cm)……………. ##.#	_____ _____ . _____

Section 2: Pregnancy Outcome Data Collection Tool (Page 1 of 2)

Q No.	Questions and Filters	Codes	Response
Identifier		Participant ID	V 3 ____ _________ ____
Participants Hospital Number		######	___ ___ ___ ___ ___ ___
201	Initials of nurse recording pregnancy outcomes.	XXX	___ ___ ___
202	Did the baby die during labor, delivery or within 7-days after labor?	Yes…………… 1 No……………. 2>>204	___
203	What was the cause of death of the baby?	Trauma from Obstructed Labor……. 1 Small for date……………………………. 2 Asphyxia…………………………………. 3 Jaundice……………………………………. 4 Infection…………………………………. 5 Sudden Infant Death Syndrome……. 6 Other………………………………………. 8 Unknown…………………………………. 9	___
204	Did the mother die during labor, delivery, or within 7-days after labor and delivery?	Yes…………… 1 No……………. 2>>206	___
205	What was the cause of death of the mother?	Obstructed Labor…………………………1 Hemorrhage / bleeding………………… 2 Preeclampsia/eclampsia…………………. 3 Other………………………………………. 8 Unknown…………………………………. 9	___
206	What is the baby's birth date? Month ………………. 01 – 13 Day…………………….01 – 30 Year…………………. ####	Birthdate ___ ___ / ___ ___ / ___ ___ ___ ___ (day) (month) (year)	

		USE ETHIOPIAN CALENDER	
207	How was the baby delivered?	Vaginally or Instrumental.........1 >>212 Caesarean Section......................2	____
208	Did the participant try labor or was a Caesarean section scheduled?	Tried labor..................... 1 >> 210 Scheduled C/S............... 2	____
209	Why was a C-section scheduled?	Contracted Pelvis.................................. 1 Large Baby... 2 Previous scar, from CPD.......................... 3 Previous scar, but no previous CPD.....4 PMTCT.. 5 Infection..6 Diabetes or hypertension......................7 Other..8 Specify ________________________________	____
210	Why was a Caesarean section performed after trail of labor? SPECIFY REASON FOR C/S IN COMMENTS SECTION ON NEXT PAGE.	Prolonged labor due to CPD........ 1 Abnormal presentation................. 2 >> 212 Fetal distress/cord prolapse....... 3 >> 212 Placental problems.......................... 4 >> 212 Failed induction............................... 5 >> 212 Other... 8 >> 212	____
211	How many hours was the participant in labor prior to C-section?	Hours......... ###	____ ____ ____

Section 2: Pregnancy Outcome Data Collection Tool (Page 2 of 2)

Q No.	Questions and Filters	Codes	Response
	IF DELIVERY BY CAESAREAN SECTION, SPECIFY, IN WORDS, THE REASON FOR C/S:		
212	What was the baby's weight **at birth**?	Weight (in kg)……………#.##	___ . ______
213	What is the baby's gender?	Male…................ 1 Female............... 2	___
214	What was the Apgar score?	Apgar................. 0 - 10	______ 1st minute ______ 5th minute
215	Were there any other complications experienced by the baby or mother during labor, delivery, or 7-days after delivery?	Yes.............. 1>> Specify below No............... 2	___
	Specify other complications or notes:		

Longitudinal Study Questionnaire

________☐ ________☐ ________☐ ________☐ ________☐

Visit 1 Visit 2 Visit 3 Visit 4 Outcome

አዲስ አበባ ዩኒቨርስቲ፣ የጤና ሳይንስ ኮሌጅ

በጥናትና ምርምር ለመሳተፍ የተዘጋጀ የተሳታፊዎች የስምምነት ሰነድ

የስምምነት ማጠቃለያ፡

"በኢትዮጵያ ውስጥ በብሔራዊ ደረጃ በምጥ ወቅት የእናት ዳሌ ከሽል ጭንቅላት ጋር አለመመጣጠንን ተከተሎ የሚከሰት አደጋ በቅድሚያ ለመተምበይ የሚረዳ ዝቅተኛ ወጪ ያለውን፣ ከንኪኪ ነፃ የሆነ ቴክኖሎጂን መጠቀም" በተሰኘው የጥናትና ምርምር ተሳትፎ እንዳደርግ ተጠይቄአለሁ። በተያያዘው በመረጃ የተደገፈ የስምምነት ሰነድ ውስጥ በተጠቀሰው መሠረት በዚህ ጥናት ውስጥ የመካተት ሥነምግባርን ግንዛቤዎችን እና ጥቅሞቹን ተረድቻለሁ እናም ይህ ምርመራ የእንቅስቃሴ ለይ የዳሌ አጥነት አወቃቀር ጠቋሚ መለኪያዎች እና የልኬት መለኪያዎችን እንደሚያካትት ተረድቻለሁ። እንዲሁም ከእኔ የተሰበሰበው መረጃ ሁሉ በሚስጢር እንደሚያዝ ተነግሮኛል።

ምክንያቶቹን ለማንም ማስረዳት ሳያስፈልግ በማንኛውም ጊዜ መረጃን የመከልከል፣ ትብብርን የመከልከል ወይም ከጥናቱ የማቋረጥ መብት እንዳለኝ፣ እና እርምጃዎቼ በእርግዝናዬ አጠቃላይ የምርመራ ሂደት ላይ ምንም ዓይነት ተጽዕኖ አንደማይኖራቸው አውቃለሁ። ደግሞም በማንኛውም ጊዜ ማብራሪያ የመጠየቅ እና የማግኘት መብት እንዳለኝ አውቃለሁ። ጥርጣሬ ወይም ጥያቄ ቢኖርብኝ ዶክተር ማህሌት ይገረሙን በ+251-911603184 ማግኘት እችላለሁ ወይም አዲስ አበባ ዩኒቨርሲቲ ጤና ሳይንስ ኮሌጅ የጥናትና ምርምር ክትትልና ፍቃድ ጽ/ቤት (አዲስ አበባ ዩኒቨርሲቲ፣ የጤና ሳይንስ ኮሌጅ፣ ጥቁር አንበሳ ስፔሻላይዝድ ሆስፒታል አዲስ ህንፃ፣ 8ኛ ፎቅ) በ25-111-15513099) ማግኘት እችላለሁ።

ማብራሪያ ጠይቄ በምረዳው ቋንቋ አጥጋቢ ምላሾች አግኝቻለሁ። መልስ ለመስጠት በቂ ጊዜ ተሰጥቶኛል። ፊርማዬን በማስቀመጥ በመጨረሻ ስምምነቴን አረጋግጣለሁ፡

____

የተሳታፊ ስም (ታትሟል)

__________________________________ _________ ___________

የተሳታፊ ፊርማ ቀን ሰዓት

__________________________________ _____________________

ስምምነትን የሚያገኝ የጥናቱ ቡድን ነርስ ፊርማ ቀን

Recruiting Nurse, fill out information below:

Participant Number: ____ ____ - ____ ____ - ____ ____ ____ ____ - ____ ____ ____

(Region ID) - (Site ID) - (Participant ID) - (Particip. Initials)

Hospital Card Number: ____ ____ ____ ____ ____ ____ Date: __ __ / __ __ / __ __ __ __ (E.C.)

Participant Phone Number: ____

Questionnaire for Traditional & 3D Anthropometry (Page 1 of 2)

Q No.	Questions and Filters	Codes	Response
101	Region ID	Addis Ababa…..01 Jimma………..04 Adama……………02 Mekelle……..05 Hawassa…………03 Gondar………06	____ ____
102	Site ID initials	Tikur Anbessa..01 Woreda 11….03 Girar………………02 Gandhi………..04	____ ____
103	Participant Identification Number	####	____ ____ ____ ____
104	Participants Initials	XXX	____ ____ ____
105	Hospital Card Number	######	___ ___ ___ ___ ___ ___
106	Nurse Initials	XXX	____ ____ ____
107	Date of recruitment & filling out this form. USE ETHIOPIAN CALENDAR	Date ___ ___ / ___ ___ / ___ ___ ___ ____ (day) (month) (year)	
108	How old was the participant on their last birthday? PROBE USING HISTORICAL EVENTS TO APPROXIMATE AGE, IF UNKNOWN	Age (in years)............... ## If not 18-40 years old >> **STOP! Exclusion Criteria**	_____ _____
109	What is the gestational age of the participant? **If 1st visit and above 24 weeks >> STOP! Exclusion Criteria** **If follow up visit and above 24 weeks, continue**	Weeks + days......... ## + #	____ ____ + ____
110	How was the gestational age determined?	Recalled days from last menstruation......... 1 Ultrasound................... 2 Other............................ 3	____
111	Is this a singleton pregnancy?	Yes.......... 1 No.......... 2 >> **STOP! Exclusion Criteria**	____
112	Is this your first pregnancy?	YES........... 1 No.......... 2 >> **STOP! Exclusion Criteria**	____
113	What region is your mother from?	Tigray......................... 01 SNNP.................... 07 Afar........................... 02 Gambella............... 08 Amhara.................... 03 Harari..................... 09 Oromia...................... 04 Addis Ababa........... 10 Somalie.................... 05 Diredawa............... 11 Benshagul Gumuz..... 06 Outside Ethiopia.... 12 Don't know.............98	____
114	What region is your father from?		____
115	Where did you live until the age of 15?		____
116	What region do you currently live in?		____
117	Does this participant plan for trial of labor?	Yes................................ 1 No................................. 2	____

118	Where does the participant plan to deliver?	Tikur Anbessa..01 Girar……………..02 Woreda 11….03	Gandhi………..04 Other………. 99 - Specify: ________	____
119	Collection Period	12-19 Weeks………………… 1 20-24 Weeks………………… 2 28-32 Weeks………………… 3 36-42 Weeks………………… 4		____
120	If Collection Period 4: What is the fetal presentation?	Vertex…………………………1 Other…………………………..2		____

Questionnaire for Traditional & 3D Anthropometry (Page 2 of 2)

Q No.	Questions and Filters	Codes	Response
	Identifier	____ ____ - ____ ____ - ____ ____ ____ ____ - ____ ____ ____ (Region ID) - (Site ID) - (Participant ID) - (Particip. Initials)	
	Collection Period	12-19 Weeks………………… 1 20-24 Weeks………………… 2 28-32 Weeks………………… 3 36-42 Weeks………………… 4	____
121	Blood Pressure from card	Systolic / Diastolic (in mmHg)……………###/###	___ ____ ____ /____ ___ ___ SYSTOLIC / DIASTOLIC
122	Height	Height (in cm)………………. ###.#	____ ____ ____ . ____
123	Weight	Weight (in kg)…………………##.#	____ ____ . ____
124	Head Circumference	Circumference (in cm)…… ##.#	____ ____ . ____
125	Shoulder Width	Width (in cm)……………….. ##.#	____ ____ . ____
126	Shoulder Height	Height (in cm)……………. ###.#	____ ____ ____ . ____
127	Waist Circumference	Circumference (in cm)…… ###.#	____ ____ ____ . ____
128	Waist Height	Height (in cm)………………..###.#	____ ____ ____ . ____
129	Hip Circumference	Circumference (in cm)…… ###.#	____ ____ ____ . ____
130	Intertrochanteric Height	Height (in cm)………………. ###.#	____ ____ ____ . ____
131	Belly Length	Length (in cm)………………..##.#	____ ____ . ____
132	Foot Length	Length (in cm)………………. ##.#	____ ____ . ____
133	COLLECT STRUCTURE SCAN. Check confirming the collection and sending of the Structure Scan to the email inbox. ☐ File name: Identifier – Collection Period (For example = 01-02-0125-MLK-3)		

134	COLLECT KINECTS SCAN. Check confirming the collection and saving of the Kinects Scan on the external hard drive. ☐ File name: Region ID – Site ID - Participant ID –Collection Period (For example = 12-0125-3)

Questionnaire for Traditional & 3D Anthropometry (Page 1 of 2)

Q No.	Questions and Filters	Codes	Response
101	Region ID	Addis Ababa…..01 Jimma………..04 Adama……………02 Mekelle……..05 Hawassa…………03 Gondar………06	____ ____
102	Site ID initials	Tikur Anbessa..01 Woreda 11….03 Girar………………02 Gandhi………..04	____ ____
103	Participant Identification Number	####	____ ____ ____ ____
104	Participants Initials	XXX	____ ____ ____
105	Hospital Card Number	######	___ ___ ___ ___ ___ ___
106	Nurse Initials	XXX	____ ____ ____
107	Date of recruitment & filling out this form. USE ETHIOPIAN CALENDAR	Date ___ ___ / ___ ___ / ___ ___ ___ ____ (day) (month) (year)	
108	How old was the participant on their last birthday? PROBE USING HISTORICAL EVENTS TO APPROXIMATE AGE, IF UNKNOWN	Age (in years)............... ## If not 18-40 years old >> **STOP! Exclusion Criteria**	_____ _____
109	What is the gestational age of the participant? **If 1st visit and above 24 weeks >> STOP! Exclusion Criteria** **If follow up visit and above 24 weeks, continue**	Weeks + days......... ## + #	____ ____ + ____
110	How was the gestational age determined?	Recalled days from last menstruation......... 1 Ultrasound................... 2 Other............................ 3	____
111	Is this a singleton pregnancy?	Yes.......... 1 No.......... 2 >> **STOP! Exclusion Criteria**	____
112	Is this your first pregnancy?	YES.......... 1 No.......... 2 >> **STOP! Exclusion Criteria**	____
113	What region is your mother from?	Tigray......................... 01 SNNP.................... 07 Afar........................... 02 Gambella............... 08 Amhara.................... 03 Harari..................... 09 Oromia...................... 04 Addis Ababa.......... 10 Somalie.................... 05 Diredawa.............. 11 Benshagul Gumuz..... 06 Outside Ethiopia.... 12 Don't know.............98	____
114	What region is your father from?		____
115	Where did you live until the age of 15?		____
116	What region do you currently live in?		____
117	Does this participant plan for trial of labor?	Yes................................ 1 No................................. 2	____

118	Where does the participant plan to deliver?	Tikur Anbessa..01 Girar………………02 Woreda 11….03	Gandhi………..04 Other……….. 99 - Specify: ________	____
119	Collection Period	12-19 Weeks………………… 1 20-24 Weeks………………… 2 28-32 Weeks………………… 3 36-42 Weeks………………… 4		____
120	If Collection Period 4: What is the fetal presentation?	Vertex………………………….1 Other…………………………..2		____

Questionnaire for Traditional & 3D Anthropometry (Page 2 of 2)

Q No.	Questions and Filters	Codes	Response
	Identifier	____ ____ - ____ ____ - ____ ____ ____ ____ - ____ ____ ____ (Region ID) - (Site ID) - (Participant ID) - (Particip. Initials)	
	Collection Period	12-19 Weeks………………… 1 20-24 Weeks………………… 2 28-32 Weeks………………… 3 36-42 Weeks………………… 4	____
121	Blood Pressure from card	Systolic / Diastolic (in mmHg)……………###/###	___ ____ ____ /____ ___ ___ SYSTOLIC / DIASTOLIC
122	Height	Height (in cm)………………. ###.#	____ ____ ____ . ____
123	Weight	Weight (in kg)…………………##.#	____ ____ . ____
124	Head Circumference	Circumference (in cm)…… ##.#	____ ____ . ____
125	Shoulder Width	Width (in cm)………………. ##.#	____ ____ . ____
126	Shoulder Height	Height (in cm)…………….. ###.#	____ ____ ____ . ____
127	Waist Circumference	Circumference (in cm)…… ###.#	____ ____ ____ . ____
128	Waist Height	Height (in cm)………………..###.#	____ ____ ____ . ____
129	Hip Circumference	Circumference (in cm)…… ###.#	____ ____ ____ . ____
130	Intertrochanteric Height	Height (in cm)………………. ###.#	____ ____ ____ . ____
131	Belly Length	Length (in cm)………………..##.#	____ ____ . ____
132	Foot Length	Length (in cm)………………. ##.#	____ ____ . ____
133	COLLECT STRUCTURE SCAN. Check confirming the collection and sending of the Structure Scan to the email inbox. ☐ File name: Identifier – Collection Period (For example = 01-02-0125-MLK-3)		

134	COLLECT KINECTS SCAN. Check confirming the collection and saving of the Kinects Scan on the external hard drive. ☐ File name: Region ID – Site ID - Participant ID –Collection Period (For example = 12-0125-3)

Questionnaire for Traditional & 3D Anthropometry (Page 1 of 2)

Q No.	Questions and Filters	Codes	Response
101	Region ID	Addis Ababa…..01 Adama……………02 Hawassa…………03 Jimma………..04 Mekelle……..05 Gondar………06	____ ____
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103	Participant Identification Number	####	____ ____ ____ ____
104	Participants Initials	XXX	____ ____ ____
105	Hospital Card Number	######	___ ___ ___ ___ ___ ___
106	Nurse Initials	XXX	____ ____ ____
107	Date of recruitment & filling out this form. USE ETHIOPIAN CALENDAR	Date ___ ___ / ___ ___ / ___ ___ ___ ____ (day) (month) (year)	
108	How old was the participant on their last birthday? PROBE USING HISTORICAL EVENTS TO APPROXIMATE AGE, IF UNKNOWN	Age (in years)……………. ## If not 18-40 years old >> **STOP! Exclusion Criteria**	_____ _____
109	What is the gestational age of the participant? **If 1st visit and above 24 weeks >> STOP! Exclusion Criteria** **If follow up visit and above 24 weeks, continue**	Weeks + days……… ## + #	____ ____ + ____
110	How was the gestational age determined?	Recalled days from last menstruation……… 1 Ultrasound……………….. 2 Other……………………….. 3	____
111	Is this a singleton pregnancy?	Yes………. 1 No………. 2 >> **STOP! Exclusion Criteria**	____
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114	What region is your father from?		____
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118	Where does the participant plan to deliver?	Tikur Anbessa..01 Girar……………….02 Woreda 11….03	Gandhi………..04 Other……….. 99 - Specify: ________	____
119	Collection Period	12-19 Weeks………………… 1 20-24 Weeks………………… 2 28-32 Weeks………………… 3 36-42 Weeks………………… 4		____
120	If Collection Period 4: What is the fetal presentation?	Vertex………………………….1 Other…………………………..2		____

Questionnaire for Traditional & 3D Anthropometry (Page 2 of 2)

Q No.	Questions and Filters	Codes	Response
	Identifier	____ ____ - ____ ____ - ____ ____ ____ ____ - ____ ____ ____ (Region ID) - (Site ID) - (Participant ID) - (Particip. Initials)	
	Collection Period	12-19 Weeks………………… 1 20-24 Weeks………………… 2 28-32 Weeks………………… 3 36-42 Weeks………………… 4	____
121	Blood Pressure from card	Systolic / Diastolic (in mmHg)……………###/###	___ ____ ____ /____ ___ ___ SYSTOLIC / DIASTOLIC
122	Height	Height (in cm)………………. ###.#	____ ____ ____ . ____
123	Weight	Weight (in kg)…………………##.#	____ ____ . ____
124	Head Circumference	Circumference (in cm)…… ##.#	____ ____ . ____
125	Shoulder Width	Width (in cm)……………….. ##.#	____ ____ . ____
126	Shoulder Height	Height (in cm)…………….. ###.#	____ ____ ____ . ____
127	Waist Circumference	Circumference (in cm)…… ###.#	____ ____ ____ . ____
128	Waist Height	Height (in cm)……………….###.#	____ ____ ____ . ____
129	Hip Circumference	Circumference (in cm)…… ###.#	____ ____ ____ . ____
130	Intertrochanteric Height	Height (in cm)………………. ###.#	____ ____ ____ . ____
131	Belly Length	Length (in cm)………………..##.#	____ ____ . ____
132	Foot Length	Length (in cm)………………. ##.#	____ ____ . ____
133	COLLECT STRUCTURE SCAN. Check confirming the collection and sending of the Structure Scan to the email inbox.		

	☐ File name: Identifier – Collection Period (For example = 01-02-0125-MLK-3)
134	COLLECT KINECTS SCAN. Check confirming the collection and saving of the Kinects Scan on the external hard drive. ☐ File name: Region ID – Site ID - Participant ID –Collection Period (For example = 12-0125-3)

Questionnaire for Traditional & 3D Anthropometry (Page 1 of 2)

Q No.	Questions and Filters	Codes	Response
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102	Site ID initials	Tikur Anbessa..01 Girar………………02 Woreda 11….03 Gandhi………..04	____ ____
103	Participant Identification Number	####	____ ____ ____ ____
104	Participants Initials	XXX	____ ____ ____
105	Hospital Card Number	######	___ ___ ___ ___ ___ ___
106	Nurse Initials	XXX	____ ____ ____
107	Date of recruitment & filling out this form. USE ETHIOPIAN CALENDAR	Date ___ ___ / ___ ___ / ___ ___ ___ ____ (day) (month) (year)	
108	How old was the participant on their last birthday? PROBE USING HISTORICAL EVENTS TO APPROXIMATE AGE, IF UNKNOWN	Age (in years)............... ## If not 18-40 years old >> **STOP! Exclusion Criteria**	_____ _____
109	What is the gestational age of the participant? **If 1st visit and above 24 weeks >> STOP! Exclusion Criteria** **If follow up visit and above 24 weeks, continue**	Weeks + days......... ## + #	____ ____ + ____
110	How was the gestational age determined?	Recalled days from last menstruation......... 1 Ultrasound.................... 2 Other............................ 3	____
111	Is this a singleton pregnancy?	Yes.......... 1 No.......... 2 >> **STOP! Exclusion Criteria**	____
112	Is this your first pregnancy?	YES........... 1 No.......... 2 >> **STOP! Exclusion Criteria**	____
113	What region is your mother from?	Tigray.......................... 01 Afar............................ 02 Amhara..................... 03 Oromia....................... 04 Somalie..................... 05 Benshagul Gumuz..... 06 SNNP..................... 07 Gambella................ 08 Harari...................... 09 Addis Ababa........... 10 Diredawa............... 11 Outside Ethiopia.... 12 Don't know..............98	____
114	What region is your father from?		____
115	Where did you live until the age of 15?		____
116	What region do you currently live in?		____
117	Does this participant plan for trial of labor?	Yes................................ 1 No................................. 2	____

118	Where does the participant plan to deliver?	Tikur Anbessa ………….. 1 Other………….. 2 - Specify: ____________	_____
119	Collection Period	12-19 Weeks………………… 1 20-24 Weeks………………… 2 28-32 Weeks………………… 3 36-42 Weeks………………… 4	____
120	If Collection Period 4: What is the fetal presentation?	Vertex…………………………1 Other…………………………..2	____

Questionnaire for Traditional & 3D Anthropometry (Page 2 of 2)

Q No.	Questions and Filters	Codes	Response
	Identifier	____ ____ - ____ ____ - ____ ____ ____ ____ - ____ ____ ____ (Region ID) - (Site ID) - (Participant ID) - (Particip. Initials)	
	Collection Period	12-19 Weeks………………… 1 20-24 Weeks………………… 2 28-32 Weeks………………… 3 36-42 Weeks………………… 4	____
121	Blood Pressure from card	Systolic / Diastolic (in mmHg)…………….###/###	___ ____ ____ /____ ___ ___ SYSTOLIC / DIASTOLIC
122	Height	Height (in cm)………………. ###.#	____ ____ ____ . ____
123	Weight	Weight (in kg)…………………##.#	____ ____ . ____
124	Head Circumference	Circumference (in cm)…… ##.#	____ ____ . ____
125	Shoulder Width	Width (in cm)……………….. ##.#	____ ____ . ____
126	Shoulder Height	Height (in cm)…………….. ###.#	____ ____ ____ . ____
127	Waist Circumference	Circumference (in cm)…… ###.#	____ ____ ____ . ____
128	Waist Height	Height (in cm)………………..###.#	____ ____ ____ . ____
129	Hip Circumference	Circumference (in cm)…… ###.#	____ ____ ____ . ____
130	Intertrochanteric Height	Height (in cm)………………. ###.#	____ ____ ____ . ____
131	Belly Length	Length (in cm)………………..##.#	____ ____ . ____
132	Foot Length	Length (in cm)………………. ##.#	____ ____ . ____
133	COLLECT STRUCTURE SCAN. Check confirming the collection and sending of the Structure Scan to the email inbox. ☐ File name: Identifier – Collection Period (For example = 01-02-0125-MLK-3)		

134	COLLECT KINECTS SCAN. Check confirming the collection and saving of the Kinects Scan on the external hard drive. ☐ File name: Region ID – Site ID - Participant ID –Collection Period (For example = 12-0125-3)

Section 2: Pregnancy Outcome Data Collection Tool (Page 1 of 2)

Q No.	Questions and Filters	Codes	Response
Identifier	____ ____ - ____ ____ - ____ ____ ____ ____ - ____ ____ ____ (Region ID) - (Site ID) - (Participant ID) - (Particip. Initials)		
Participants Hospital Number		######	____ ____ ____ ____ ____ ____
201	Initials of nurse recording pregnancy outcomes.	XXX	____ ____ ____
202	Did the baby die during labor, delivery or within 7-days after labor?	Yes............... 1 No................ 2>>204	____
203	What was the cause of death of the baby?	Trauma from Obstructed Labor....... 1 Small for date.................................... 2 Asphyxia... 3 Jaundice.. 4 Infection.. 5 Sudden Infant Death Syndrome....... 6 Other.. 8 Unknown... 9	____
204	Did the mother die during labor, delivery, or within 7-days after labor and delivery?	Yes............... 1 No................ 2>>206	____
205	What was the cause of death of the mother?	Obstructed Labor.............................1 Hemorrhage / bleeding.................... 2 Preeclampsia/eclampsia..................... 3 Other.. 8 Unknown... 9	____
206	What is the baby's birth date? Month .... 01 – 13 Day.........................01 – 30 Year...................... ####	Birthdate ___ ___ / ___ ___ / ___ ___ ___ ___ (day) (month) (year) **USE ETHIOPIAN CALENDER**	
207	How was the baby delivered?	Vaginally or Instrumental.........1 >>212 Caesarean Section......................2	____
208	Did the participant try labor or was a Caesarean section scheduled?	Tried labor.................... 1 >> 210 Scheduled C/S............... 2	____
209	Why was a C-section scheduled?	Contracted Pelvis................................ 1 Large Baby.. 2 Previous scar, from CPD....................... 3 Previous scar, but no previous CPD.....4 PMTCT... 5 Infection..6 Diabetes or hypertension.....................7 Other..8 Specify ______________________	____
210	Why was a Caesarean section performed after trail of labor? SPECIFY REASON FOR C/S IN COMMENTS SECTION ON NEXT PAGE.	Prolonged labor due to CPD........ 1 Abnormal presentation................. 2 >> 212 Fetal distress/cord prolapse....... 3 >> 212 Placental problems......................... 4 >> 212 Failed induction.............................. 5 >> 212 Other.. 8 >> 212	____
211	How many hours was the participant in labor prior to C-section?	Hours......... ###	____ ____ ____

Section 2: Pregnancy Outcome Data Collection Tool (Page 2 of 2)

Q No.	Questions and Filters	Codes	Response
	IF DELIVERY BY CAESAREAN SECTION, SPECIFY, IN WORDS, THE REASON FOR C/S:		
212	What was the baby's weight **at birth**?	Weight (in kg)……………#.##	___ . _______
213	What is the baby's gender?	Male………………. 1 Female…………… 2	___
214	What was the Apgar score?	Apgar……………… 0 - 10	_______ 1st minute _______ 5th minute
215	Were there any other complications experienced by the baby or mother during labor, delivery, or 7-days after delivery?	Yes…………… 1>> Specify below No……………. 2	___
	Specify other complications or notes:		

Training Manual

CPD Project – Training

1

Goals of Training Program

- Learn how to accurately utilize the technology to take accurate measurements
  - Tape measurements
  - Structure
  - Kinect
- Learn how to manage study data
- Learn how to tackle common issues that may occur

2

Purpose of Study

- Why? = Help moms know if they are at high risk for needing C/S
- How?
  - Obtain measurements of mother's body
  - Use these measurements to create a "risk score" that indicates how likely a woman is to develop obstructed labor from CPD
  - Mothers can use this risk score to understand their unique need to go to a hospital for delivery, so that C/S is available
- Risk score created through very accurate tape measurements, and very high-quality 3D images obtained during their ANC visits.
  - Study relies on these measurements being excellent

3

Background on Technology

Tape Measure	Structure	Kinect
		

4

Questions?

5

Recruitment

6

Inclusion / Exclusion

- Inclusion:
  - All premie mothers
  - Delivery at Black Lion
  - Trying labor
- Exclusion
  - Mother has disease
  - Not singleton – twins, triplets
  - Not trying labor
  - No delivery at black lion
  - Not premie
  - Fetal status – hydrocephalus
  - All cases that indicate C/S

7

Questions

8

Informed Consent

9

Introduction – Informed Consent

Study Information Sheet

Explain:

- Introduce yourself
- Purpose of study
- Benefit of participating
- Procedure
- Safety & Security

10

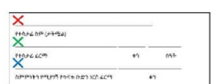
Introduction – Informed Consent

- Common questions
  - Do I have CPD?
    - Explain that we **cannot** offer clinical advice
    - Only can generally explain general danger signs, and encourage them to come to the hospital
  - How is my pregnancy? Am I healthy?
    - Again, explain that we **cannot** offer clinical advice

11

Introduction – Informed Consent

Consent Form



Subject Name (Printed)

Subject Signature Date Time

Nurse Signature Date

12

Questions?

13

Eligibility Questionnaire

14

Eligibility Questionnaire – Overview

Study Information Sheet

Use a combination of asking subject for information, and getting information from their hospital card

15

Questionnaire for Traditional & 3D Anthropometry (Page 1 of 2)

Q No.	Questions and Filters	Codes	Response
101	Region ID	Addis Ababa.....01 Adama..............02 Hawassa...........03 Jimma..........04 Mekelle........05 Gondar.........06	___ ___
102	Site ID initials	Tikur Anbessa..01 Girar..................02 Woreda 08....03 Other............99	___ ___
103	Participant Identification Number	####	___ ___ ___ ___
104	Participants Initials	XXX	___ ___ ___
105	Hospital Card Number	######	___ ___ ___ ___ ___ ___
106	Nurse Initials	XXX	___ ___ ___
107	Date of recruitment & filling out this form. USE ETHIOPIAN CALENDAR	Date ___ ___/___ ___/___ ___ ___ ___ (day) (month) (year)	

16

108	How old was the participant on their last birthday? PROBE USING HISTORICAL EVENTS TO APPROXIMATE AGE, IF UNKNOWN	Age (in years)............... ## If not 18-40 years old >> **STOP! Exclusion Criteria**	___ ___
109	What is the gestational age of the participant? **If 1st visit and above 24 weeks >> STOP! Exclusion Criteria** **If follow up visit and above 24 weeks, continue**	Weeks + days......... ## + #	___ ___ + ___
110	How was the gestational age determined?	Recalled days from last menstruation......... 1 Ultrasound.................... 2 Other............................ 3	___
111	Is this a singleton pregnancy?	Yes.......... 1 No........... 2 >> **STOP! Exclusion Criteria**	___
112	Is this your first pregnancy?	YES.......... 1 No........... 2 >> **STOP! Exclusion Criteria**	___

17

113	What region is your mother from?	Tigray...................... 01 Afar........................ 02 Amhara.................... 03 Oromia..................... 04 Somalie.................... 05 Benshagul Gumuz..... 06 SNNP..................... 07 Gambella.............. 08 Harari..................... 09 Addis Ababa.......... 10 Diredawa............... 11 Outside Ethiopia.... 12 Don't know.............98	___
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115	Where did you live until the age of 15?		___
116	What region do you currently live in?		___
117	Does this participant plan for trial of labor?	Yes................................ 1 No................................. 2	___
118	Where does the participant plan to deliver?	Tikur Anbessa .... 1 Other............... 2 - Specify: ___________	___
119	Collection Period	12-16 Weeks..................... 1 20-24 Weeks..................... 2 28-32 Weeks..................... 3 36-42 Weeks..................... 4	___
120	If Collection Period 4: What is the fetal presentation?	Vertex...............................1 Other................................2	___

18

Questions?

19

Anthropological Measurements

20

Questionnaire for Traditional & 3D Anthropometry (Page 2 of 2)

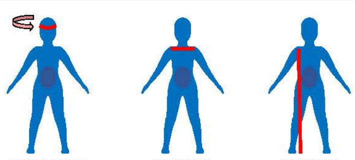
Q No.	Questions and Filters	Codes	Response
	Identifier	___ ___ - ___ ___ - ___ ___ ___ ___ - ___ ___ ___ (Region ID) - (Site ID) - (Participant ID) - (Particip. Initials)	
	Collection Period	12-16 Weeks.................... 1 20-24 Weeks.................... 2 28-32 Weeks.................... 3 36-42 Weeks.................... 4	___
121	Blood Pressure from card	Systolic / Diastolic (in mmHg)................###/###	___ ___ ___/___ ___ ___ SYSTOLIC / DIASTOLIC
122	Height	Height (in cm).................... ###.#	___ ___ ___.___
123	Weight	Weight (in kg)......................##.#	___ ___.___

21

122	Height	Height (in cm).................. ###.#	___ ___ ___.___
123	Weight	Weight (in kg)...................##.#	___ ___.___

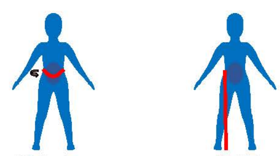
22

124	Head Circumference	Circumference (in cm)...... ##.#	___ ___.___
125	Shoulder Width	Width (in cm)..................... ##.#	___ ___.___
126	Shoulder Height	Height (in cm).................. ###.#	___ ___ ___.___



23

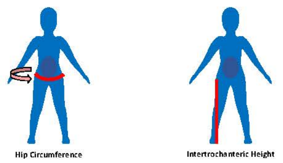
127	Waist Circumference	Circumference (in cm)...... ###.#	___ ___ ___.___
128	Waist Height	Height (in cm)....................###.#	___ ___ ___.___



24

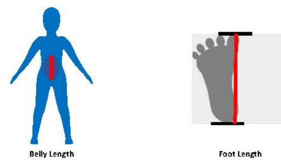
4

129	Hip Circumference	Circumference (in cm)...... ###.#	___ ___ ___ . ___
130	Intertrochanteric Height	Height (in cm).................. ###.#	___ ___ ___ . ___

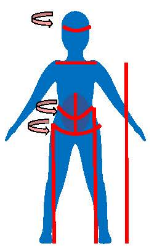


25

131	Belly Length	Length (in cm)...................##.#	___ ___ . ___
132	Foot Length	Length (in cm).................. ##.#	___ ___ . ___



26



27

Questions?

28

Structure Scanner

29

How it works

- Camera on iPad takes 3D picture of subject

30

Preparation – Charging devices

- Devices should be plugged in whenever you are not using them

31

Preparation – Attach Structure Sensor to iPad

32

Preparation – Charging while attached

33

Preparation – Room setup

- Place sheet down over the floor
- Ask patient to disrobe and stand at designated scanning location
  - Need enough space around the subject that you can go all the way around
- Ask patient to be in proper scanning position
  - Arms 45 degree angle from floor
  - Legs spread apart
- Place box in front of subject

34

How to Scan

3 most important things to remember about Structure Scanning:

- **Star** – Ensure subjects are in the proper **"star" position**
- **Still** – Ensure subjects **do NOT move** during scanning
- **Slow –** Scan the patient **very slowly,** ensuring the picture is complete before continuing to circle the patient!

35

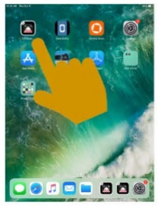
How to Scan

1. Instruct patient to stand at X location, in proper "star" position, and to NOT MOVE
2. Place "box" in front of patient's feet

36

How to Scan

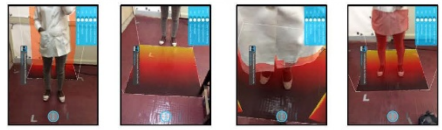
2. Open iPad app



37

How to Scan

3. Position patient's feet inside the box, and ensure the entire box is visible



BAD Not in box

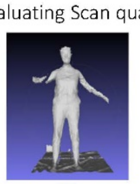
BAD Not in box

BAD Too close, entire box not visible

GOOD In box perfectly!

38

Evaluating Scan quality



BAD
Subject moved → arms incorrect

Make sure subjects don't move during scanning!

BAD
Nurse scanned too fast → scan has holes (especially in head)

Scan slowly!

39

Evaluating Scan Quality

BAD
Subject in bad position → scan incorrect

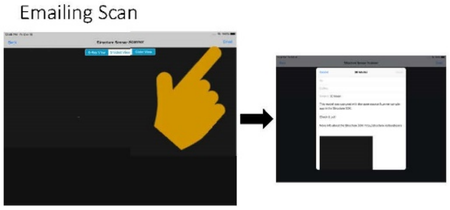
Make sure subject stays in "star" position!

GOOD
Nurse scanned slowly, patient in correct position and didn't move → scan is perfect!

Remember: Star, Still, Slow!

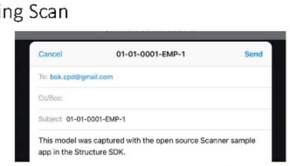
40

Emailing Scan



41

Emailing Scan



1. **Change "To:" to EXACTLY: bok.cpd@gmail.com**
2. **Change "Subject:" to Identifier – Period**

___ ___ - ___ ___ - ___ ___ ___ ___ - ___ ___ ___ - ___
(Region ID) - (Site ID) - (Participant ID) - (Particip. Initials) - (Period)

42

Questions?

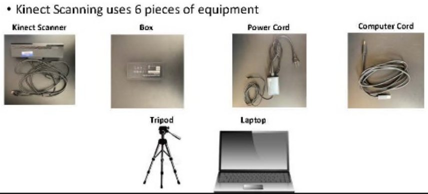
43

Kinect Scanner

44

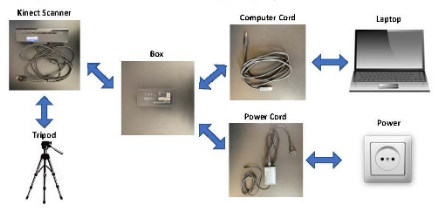
Preparation – Assembling Equipment

- Kinect Scanning uses 6 pieces of equipment



45

Preparation – Assembling Equipment



46

Preparation – Assembling Equipment

47

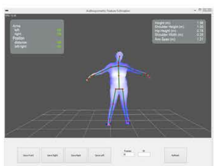
Preparation – Room setup

- Place sheet down over the floor
- Ask patient to disrobe and stand at designated scanning location
- Ask patient to be in proper scanning position
  - Arms 45 degree angle from floor
  - Legs spread apart
- Ensure Kinect is at proper predetermined location, as indicated by tape

48

How to take scan

1. Open the "Anthropometric Scanning" application on the desktop of the computer. Program will open.
2. Ensure subject is standing at proper position – patient will turn Blue when they are in proper position.



49

How to scan (cont.)

3. Under "Frames" write 20, and under "ID" write "PatientID – Initials Period"

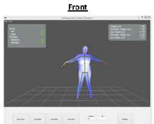
   ie 0001-EMP1 if first subject, initials EMP, and at first visit

4. Repeat for front, side, and back.

50

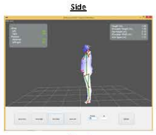
Kinect – Evaluating Scan Quality

Front



Good

Side



Good

Back

Good

51

Kinect – Evaluating Scan Quality

Ensure subject is not too far or too close from Kinect scanner

BAD - Too far

BAD - Too close

52

Kinect – Evaluating Scan Quality

Ensure subject arms are in correct position

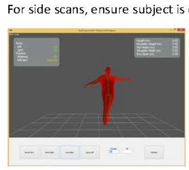
BAD – Arms are too high

GOOD – arms are in correct position

53

Kinect – Evaluating Scan Quality

For side scans, ensure subject is completely turned to the side



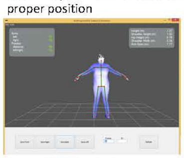
BAD – Not completely turned to the side

GOOD – Subject completely facing side

54

Kinect – somewhat correct (need to go through it still)

Scans may be "blue" but still BAD – you still need to ensure subject is in proper position



BAD – Subject looking down

BAD – Legs too close together

55

Kinect – Evaluating Scan Quality

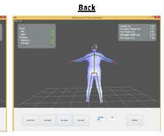
Front

Good

Side

Good

Back



Good

56

Questions?

57

Data Management

58

Longitudinal Study - Overview

- Hope to take measurements of women at all 4 ANC visits
  - Visit 1 = 12-15 weeks
  - Visit 2 = 20-24 weeks
  - Visit 3 = 28-32 weeks
  - Visit 4 = 26-42 weeks

59

Recruitment

- Recruitment = any time within 12-24 weeks
  - If 12-19 weeks, period 1
  - If 20-24 weeks, period 2
    - We just won't have any data for period 1 for that patient, it's okay

60

Strategy for following subjects

- Write date on questionnaires
- Record phone numbers of subjects
- Keep track of who to expect to be coming back each week by writing predicted date on the questionnaires
- Data manager (EP) will have spreadsheet to check in with you to see if people are coming back when they should be

61

Scanning forms & data entry

- Go through how to do on app
- Practice one ipad each – scanning and data upload
- Practice using equipment on me

62

Scanning with Genius Scan

- Explanation of how
- Important things to note
  - Make sure that you can visibly see the numbers

63

Data Entry

- Explain how to go to app, etc.
- How it will get mad if you do it wrong

64

Payment

- Don't explain payment until the end
  - At the end, say payment is for support Ethiopian women for next generation, for the time lost from participating in the study

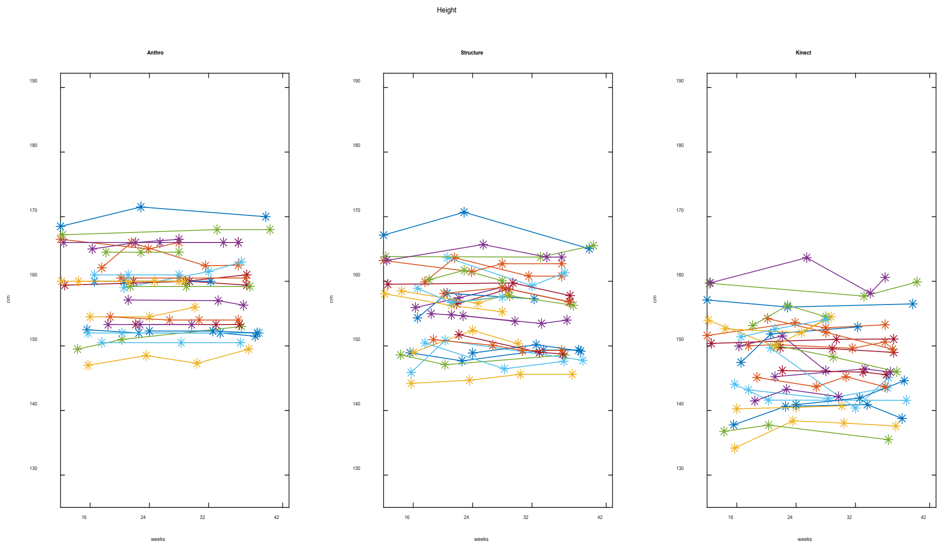
65

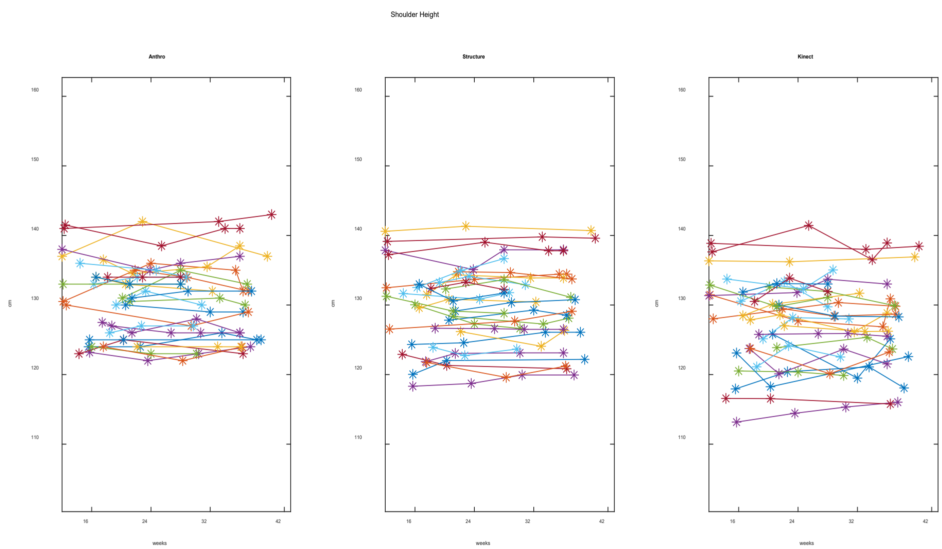
Follow-up

- Explain how to go about following-up with patient
  - (need to get more details from nurses on how they think we should train for this)

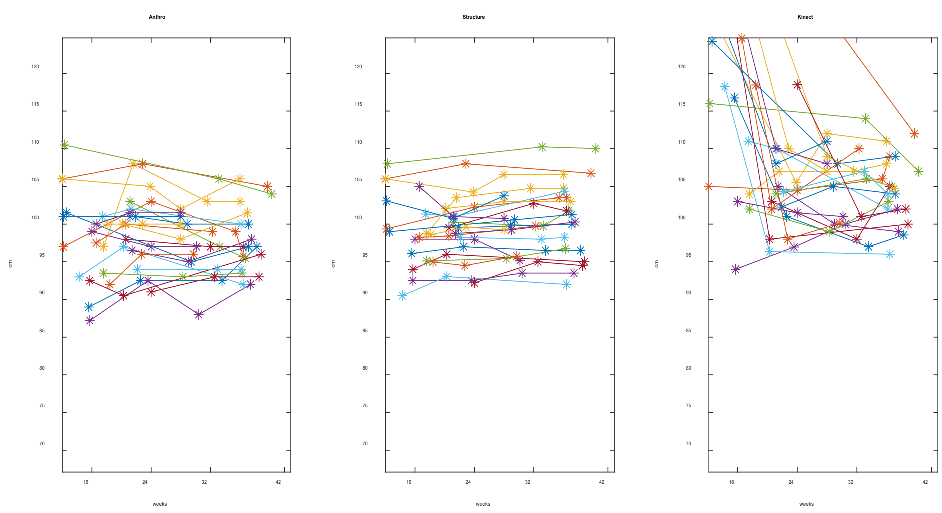
66

Longitudinal Analysis

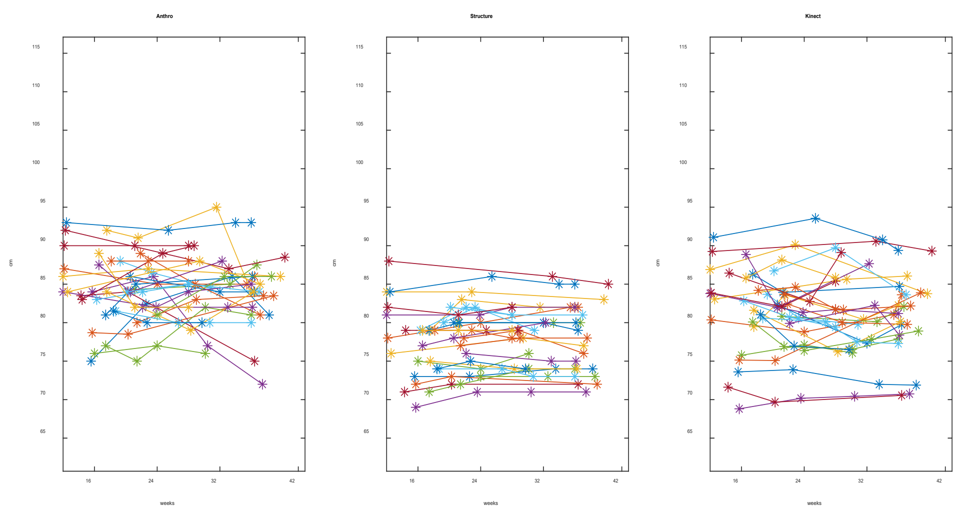




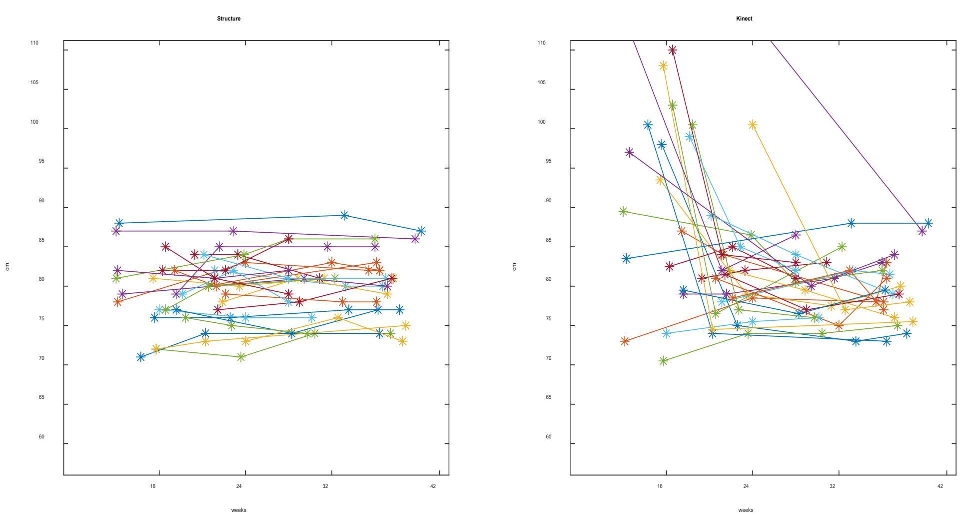
Waist Height



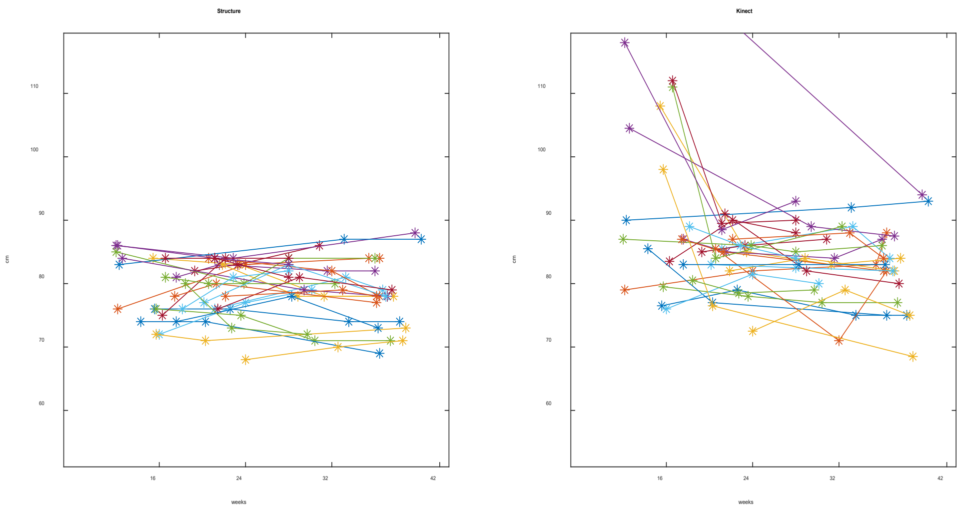
Hip Height



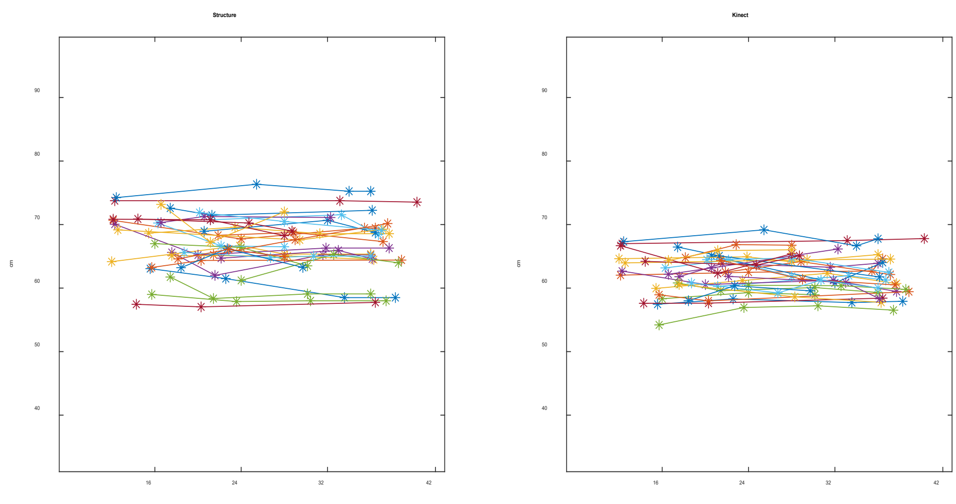
L5S1 Height



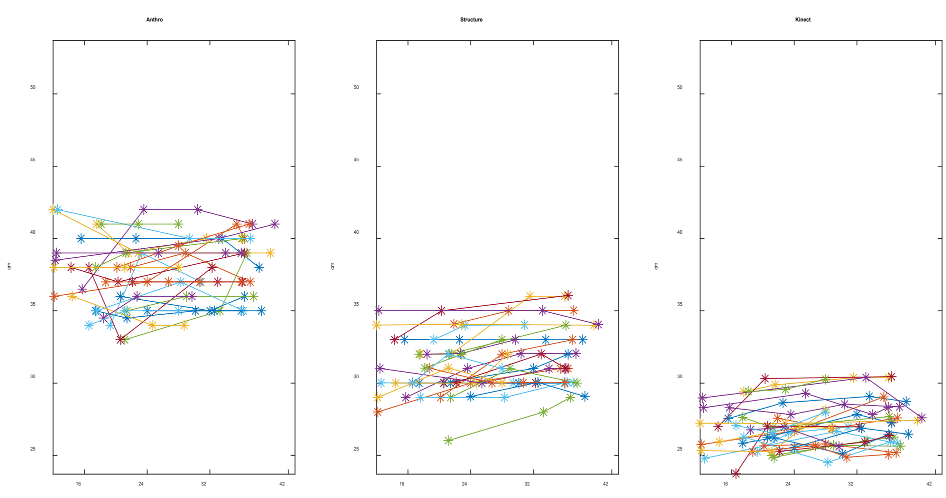
Symphysis Height



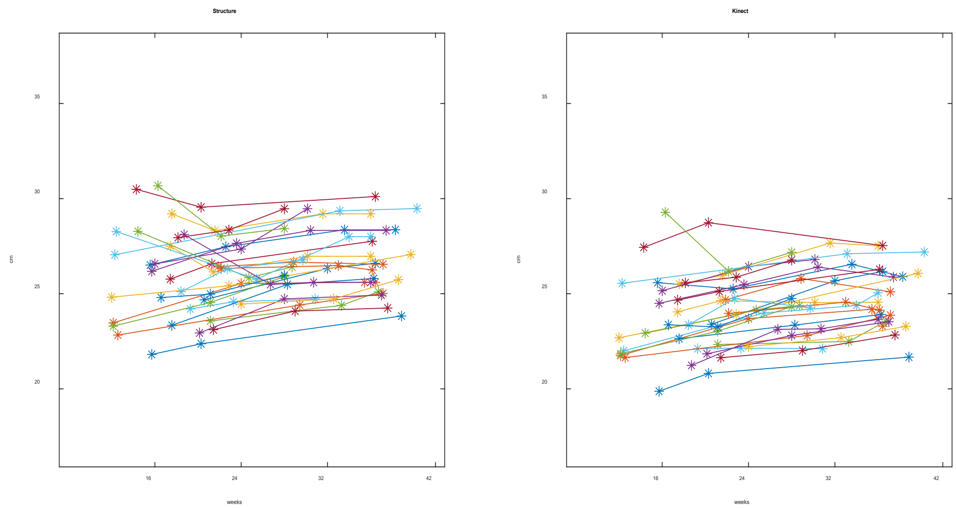
VPoint Height



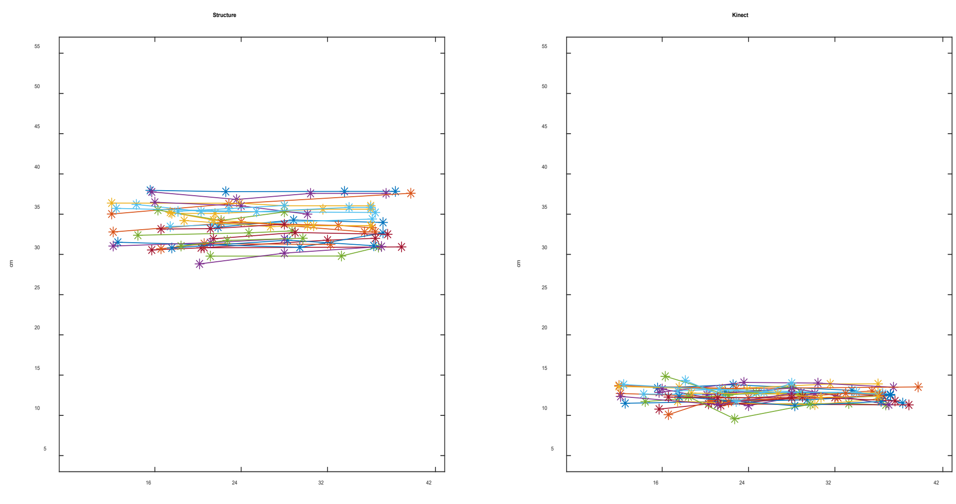
Shoulder Diameter



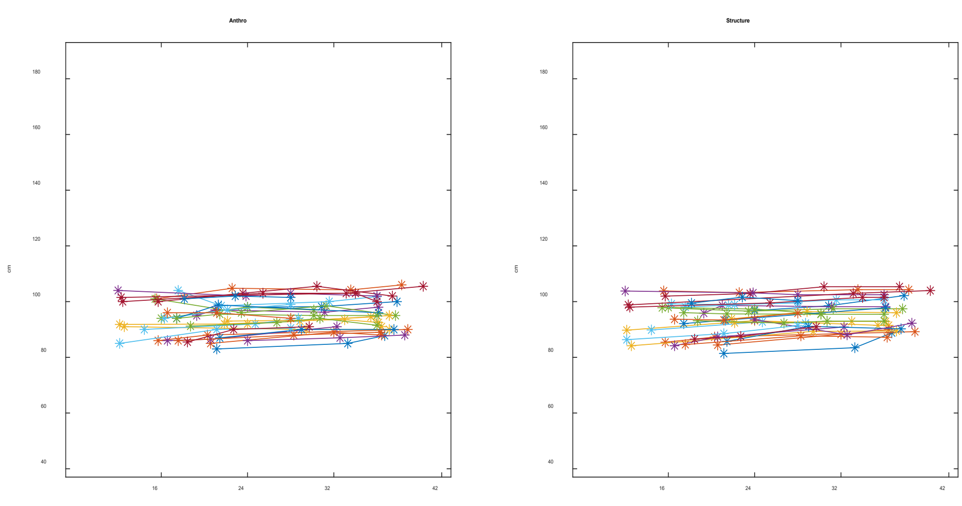
Waist Diameter



Hip Diameter



Hip Circumference



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